Department for Environment Food & Rural Affairs

Ricardo Energy & Environment

Evidence review on effectiveness of transport measures in reducing nitrogen dioxide

Appendix 1 to project summary report for contract AQ0959 'Exploring and appraising proposed measures to tackle air quality'

May 2016

This publication is available at https://uk-air.defra.gsi.gov.uk and http://randd.defra.gsi.gov.uk
Any enquiries for Defra regarding this publication should be sent to: air.quality@defra.gsi.gov.uk

Customer:

Department for Environment, Food and Rural Affairs

Customer reference:

AQ0959

Confidentiality, copyright & reproduction:

Disclaimer:
The views in this report are the authors' own and do not necessarily reflect those of the Department for Environment, Food and Rural Affairs.

Contact:

Beth Conlan
Ricardo Energy & Environment
Gemini Building, Harwell, Didcot, OX11 0QR, United Kingdom

t: +44 (0) 1235 75 3480
e: Beth.Conlan@ricardo.com

Ricardo-AEA Ltd is certificated to ISO9001 and ISO14001

Author:

Conlan, B., Fraser, A., Vedrenne, M., (Ricardo Energy & Environment), Tate, J. (ITS University of Leeds) Whittles, A., (LES Ltd).

Approved By:

Beth Conlan

Date:

12 May 2016

Ricardo Energy & Environment reference:

Ref: ED60017- Issue Final

Executive summary

A literature review was undertaken to seek evidence of the impact of measures to reduce NO_x emissions in pursuit of compliance with the EU limit values on nitrogen dioxide set for the protection of human health. In particular the following research questions were asked:

Primary research question:

- *What quantifiable effect might a range of policy measures potentially have on NO_2 concentrations?*

Secondary research questions:

- *What quantifiable effect might the specified policies have on perceptions or behaviours amongst the general public, specific transport user groups or other stakeholders?*
- *What quantifiable effect might the specified policies have on traffic flows, composition and speed?*
- *What quantifiable effect might the specified policies have on NO_X emissions?*
- *What are the unintended consequences, including effects on other pollutants and other environmental/ social effects? Are there any disproportionate impacts on particular groups of people/organisations?*
- *What are the contributory factors (triggers and barriers) to effective implementation of a package of measures to reduce NO_2 concentrations at both a local and national level?*

This report presents key findings on the effectiveness of a wide range of measures to improve air quality, based on the evidence available. Over 400 academic papers were reviewed for the impact of 72 policy measures to improve air quality. Many measures were found to be potentially effective to a greater or lesser extent, and where evidence was weak this was not taken to mean ineffectiveness. Confounding factors were examined, such as the failure of the Euro standards to deliver real world NO_X emission reductions, so that the *potential* for measures was evaluated. On the whole, quantitative evidence post implementation of a measure was lacking in the literature. However, information from the implementation of local measures across the UK over the past 15 years was used to determine a sense of scale of measures' impacts on air quality improvements.

The areas that appear to offer the most potential to reduce NO_2 concentrations in the more highly polluted areas of the UK, based on literature and expert opinion, focus on reducing the demand for use of diesel vehicles in those areas, particularly passenger cars in the fleet, and promoting alternative fuels/technologies:

- Accelerating the uptake of Euro 6 for light duty (cars and vans) and Euro VI for heavy-duty (lorries, coaches and buses) vehicles, in areas most affected by air pollution;
- Increasing the uptake of hybrid powertrains[1]. For buses in particular, hybrid powertrains should be NO_X and CO_2 optimised for urban duty cycles. For cars, petrol hybrids but not diesel hybrids should be encouraged (there is no evidence that diesel car hybrid powertrains have lower NOx than conventional diesel cars); and
- Greening taxi fleets, particularly for operation in pollution hot-spots.

Traffic management and access control measures (such as vehicle restricted areas, low emission zones and parking management) physically reduce or remove the source of the air pollution problem. As such they can be very effective and when combined with redevelopment of an area, they can have wider quality of place and economic benefits. However, the literature suggests they can be expensive

[1] In a motor vehicle, the term **powertrain** describes the main components that generate power and deliver it to the road surface, water, or air. This includes the engine, transmission, drive shafts , differentials , and the final drive (drive wheels, continuous track military tanks or caterpillar tractors, propeller etc. (Wikipedia, accessed 2014)

to implement and because of their restrictive nature can be politically unpopular if not handled sensitively with considerable consultation and engagement.

The promotion of low emission vehicles (e.g. with grants, fiscal incentives, labelling schemes) is a technology 'fix'. Replacing conventional vehicles with low emission vehicles can generate significant emission and air quality benefits if taken up substantially. However, such measures are not always as effective as expected due to low uptake, and many of the alternative technologies are still proving costly. They also do not provide the additional local benefits such as reduced congestion or increased levels of physical activity. However, at the national level they can provide economic benefits in terms of the development, production and servicing of new vehicle technologies.

Demand management measures and measures to encourage shift away from single person car use to other transport modes (walk, cycle, bus, train) can be very cost effective and can have a wide range of benefits from reduced congestion, improved air quality, reduced carbon emissions and increased levels of physical activity (section 2.2). Some of these measures, such as development control and land use planning realise air quality improvements over the longer term. Other measures, such as freight management, can have shorter term impact. However, travelling attitudes and habits are often very deep rooted and can be hard to change; comprehensive packages of measures which include a focus on travel option information e.g. personalised travel planning or eco-driving can help to address this. However, the emissions benefit of such information campaigns may tail off over time. Also, although significant impacts in terms of travel behaviour changes have been seen, directly related improvements in air quality have not always been observed. In some cases NO_2 concentration benefits may have been too small to perceive.

Pricing mechanisms can influence the purchase choice of vehicles and their use and is considered a very cost effective measure as they rely on an existing tax system of vehicle tax and fuel duty. Shifting taxation to favour low NO_x emission cars, particularly for company car sales, which represent over 50% of all new car sales would seem a very cost effective measure. However, the literature shows that the use of national pricing mechanisms needs to be done with care with many authors reporting unintended consequences resulting in a negative impact on social equality. For local or regional schemes, such as road tolls, schemes need to be designed with care to discourage pollutant emission displacement where drivers use alternative routes to avoid tolls.

These measures are not mutually exclusive: studies show that transport interventions are often combined in the aim of achieving a greater impact. For example a programme aimed at encouraging drivers to reconsider their journeys and vehicles can also be used to promote low emission vehicles; a bus quality partnership may generate improvements in overall bus services, encouraging users of less sustainable modes of transport to switch to buses, as well potentially improving the emission standards of the buses. The assessment of local measures implemented in the UK as reported in Local Authority Action Plans suggests that most existing measures on their own may only generate a small reduction in road vehicle emissions. Indeed, the evidence suggests that greater reductions in NO_X and improvements in air quality may occur when a number of measures are integrated and packaged together. For example, a low emission zone designed to target the higher polluting vehicles can be supported by a package of complementary measures. Such complementary measures can include: improvements in walking, cycle, bus and train facilities; traffic management and pricing mechanisms (to discourage, for example, zone peripheral parking, and peripheral cut through routes); and incentives to encourage uptake to meet vehicle emission compliance such as retrofit or scrappage schemes. If designed appropriately, such measures not only reduce air pollutant emissions but can also provide climate change benefits as well as wider benefits such as noise reduction, congestion alleviation and economic development.

In general, it is challenging to assess the effects of specific policies on NO_2 concentrations following implementation because of various confounding effects, including the influence of meteorology or atmospheric chemistry and changes in emissions resulting from other policy measures. More research and analysis is needed on air pollution concentrations pre- and post-implementation of measures to firm up the evidence base correlating take-up with impacts.

Table of contents

1 Introduction

1.1 Background

There is clear evidence that there is a causal relationship between exposure to air pollution and health impacts. The Committee on the Medical Effects of Air Pollutants (COMEAP) has confirmed the evidence has strengthened in recent years associating exposure to nitrogen dioxide (NO_2) with health effects (COMEAP, 2015). The effect on mortality of current levels of exposure to $PM_{2.5}$ and NO_2 concentrations in the UK is estimated to be equivalent to 29,000 and 23,500 deaths annually respectively (figures not additive, Defra, 2015).

This project, conducted by Ricardo Energy & Environment on behalf of Defra, reviewed evidence of the effectiveness of road transport policy measures to improve air quality, and developed tools – informed by the evidence gathered – to assist in the selection of measures and to estimate the effects of such measures on air quality. The overall project findings and outputs are summarised in the main report. This appendix describes the methodology and findings from the first stage evidence review in more detail.

1.2 Methodology

The Civil Service guidance on Rapid Evidence Assessment (Civil Service, 2014) and the guidance prepared by the Joint Water Evidence Group on 'The Production of Quick Scoping Reviews and Rapid Evidence Assessments: A How to Guide' have been followed in the review when appropriate. Particular elements of the approach are set out more detail in annex 1 to this report.

Sources of literature

The literature search included the following two strands of UK, European and international sources:

- On-line database (Science Direct, PubMed, Scopus) of published scientific articles
- Grey literature (reports) identified through publicly available websites, the reference library of the Project team, contacting relevant organisations (e.g. Environment Agency, GLA, TfL, SEPA, Transport Scotland, Devolved Administrations) and the EC catalogue of air quality measures (European Commission, 2014).

Search strategy - screening and ranking of articles

The literature search through the use of on-line databases generated a large number of articles. The number of articles was reduced to a more manageable number by applying the search terms for a policy measure, together with different Boolean operations of the search term for an area of application (e.g. only vehicles) and a policy outcome (e.g. air pollution or journeys). The articles identified were then screened using a staged approach.

Science Direct was used as the primary on-line database to identify articles published after the year 2000. The search engines, PubMed and Scopus, were later used to supplement the literature search. Google scholar was tested; the results were less focused including MSc thesis of unknown quality ranking above the key papers in the field. It was not felt that Google Scholar added anything to the academic literature review.

The search criteria and terms used with the on-line databases to identify relevant articles were structured in terms of:

- Policy Measures/Levers e.g. taxation, regulation, incentives
- Areas of Application (namely, the modes of transport)
- Policy Outcomes

Decisions on the inclusion or exclusion of papers based on the search criteria were made in duplication based on the title and abstract. Further information on the number of papers searched are provided in Annex 2.

Screening Approach

The focus of this study was to review the evidence of measures which have resulted or have the potential to result in a positive impact to reduce NOx emissions. The criteria to assess this are given in Annex 2. Papers were judged acceptable if there was robust evidence of a potential impact on NO_2. These were then prioritised according to the remaining screening criteria in Table 1.

Table 1: Literature review measure screening criteria

Inclusion/exclusion criteria for literature selection
Has robust evidence been gathered as part of the screening review to assess the impact on NO_2 or factors that affect NO_2?
Is the measure applicable at the national scale?
Would impact be localised or widespread?
Is the impact sufficient for the measure to be considered effective?

Limitations of the evidence

It should be noted that many measures considered are not focused specifically on reducing air pollution but rather on other impacts such as easing congestion. In many cases their specific impact on air pollution has not been directly considered and reported in the literature. Also the nature of an air pollution problem can be very local and specific. Therefore, any given package of measures will need to reflect this local situation to provide an effective solution. Similarly the impact and potential cost of measures will relate to the local context. There may be common themes that can be drawn out and these will drive wider policy and measures at the national level.

Additional limitations are that a measure's effectiveness depends on its design and implementation in relation to the place it is being implemented; therefore lack of effectiveness in one case does not mean that particular measure has no potential to be effective in another case. There are many evidence gaps even on relatively common measures. The review is necessarily limited to cases of measures that have been studied robustly.

Timeframe for literature search

The commencement of the literature search was 1 September 2014 with a cut off searching and extraction time of 30 November 2014. Papers prior to the year 2000 were not included in the initial library search. Findings were analysed and presented to Defra. However, there was an extended period between the evidence review activity and finalisation of this project, which enabled a further limited review of the most recent literature during 2015 and early 2016. Papers which were deemed to be of significant importance to the key findings were included in the final analysis and are presented accordingly.

1.3 Structure

This report documents the findings of a Rapid Evidence Review.

Section 1 of the report gives the background of the project. A long list of policy measures have been considered in this study as outlined in Annex 1. Section 2 considers an initial screening of measures to identify those with most potential to improve air quality. Sections 3 and 4 outline findings from the evidence review on the packages of measures that appear to have the greatest potential to improve air quality on pricing mechanisms and low emissions zones. These sections also include complementary measures such as vehicle scrappage, retrofit and incentivising the uptake of low emission vehicles. Section 5 sets out the conclusions from the literature and the gaps in the evidence base.

2 Initial screening of potential effectiveness of categories of measures

This section sets out a framework for the consideration of measures to improve air quality which were grouped according to themes. Questions were formulated and presented to assist in the decision of whether a paper was included or excluded from the review, as set out in section 1.2. For papers included, these questions were used to extract relevant information from the papers. Results from this rapid screening are presented in section 2.2-2.5.

2.1 Thematic frameworks

The evidence review was conducted for measures set out in Annex1 which fall under the following four themes:

- Reduce demand for more polluting forms of transport
- Reduce emissions from existing vehicles
- Promote vehicles with low emissions
- Displace pollutant emissions outside hot spots and populated areas

All measures outlined in Annex 1 have been considered in this section and those deemed to have a high potential impact to reduce NO_x emissions are considered in further detail in Section 3 and 4 of this report. All measures suggested for review are those focussed on transport emissions.

Transport is a major source of air pollution in urban areas across the UK and much of Europe. As such, transport has a significant role to play in solving these problems and improving air quality and public health. In the UK it is estimated within the National Atmospheric Emissions Inventory that road transport contributes around 40% of total national emissions of NO_x (NAEI, 2013). However it plays a much greater role in air pollution problems as transport emissions are concentrated on the road network in the country's towns and cities. Of the 690 local air quality management areas declared in the UK some 95% are a result of transport activity (Defra, 2013). The cost of this urban transport related air pollution to human health is estimated at between £4.5 and £10 billion annually to the UK economy (Cabinet Office, 2009).

Consultation with the Environment Agency as part of this study indicated no knowledge of recent research on measures to reduce NO_x emissions from industrial sources. However, while the focus of this study is on measures to reduce transport emissions it is accepted that, as the challenge to compliance is high in some areas, control of all sources of emissions could be of benefit.

Within road transport, heavy duty vehicles and buses are the main source of NO_x emission contributing to NO_2 concentrations, but in absolute terms this has been reducing. Diesel cars are now the second biggest source of NO_x emissions and this source has grown rapidly over the last 15 years (NAEI, 2013).

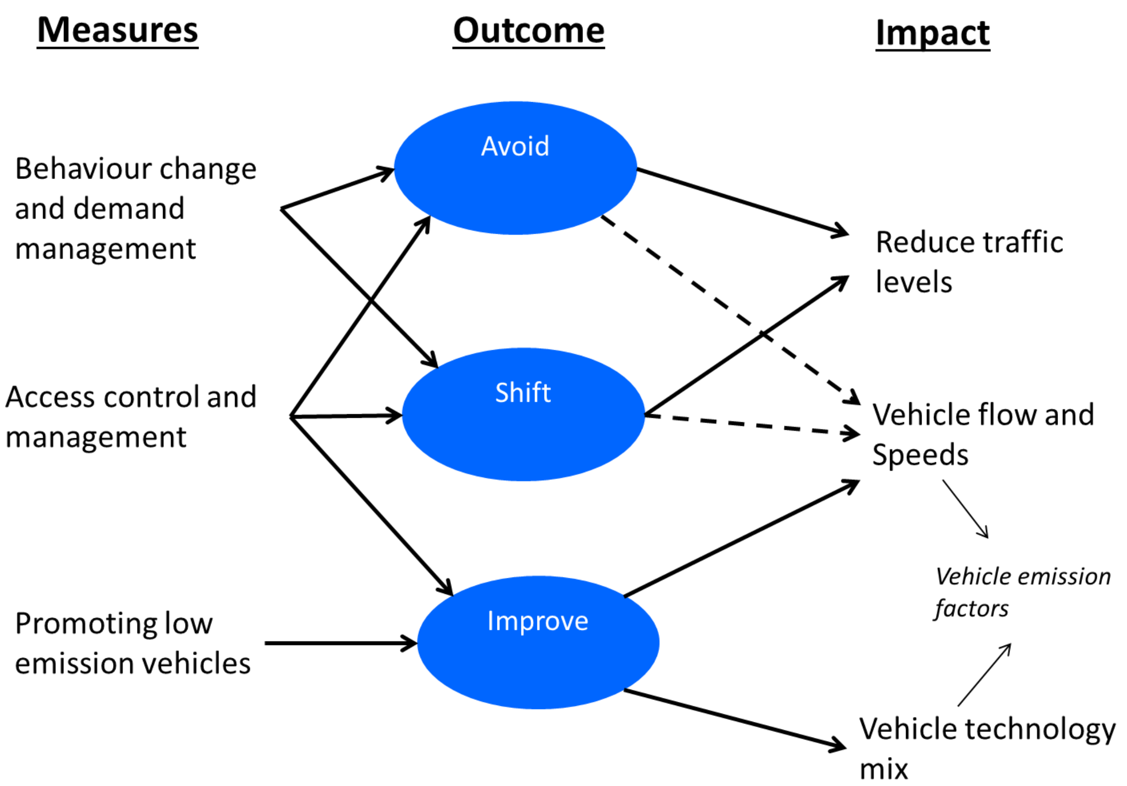
Another commonly used framework is the 3-pillar system known as Avoid-Shift-Improve (Dalkmann & Brannigan, 2007; UNEP, 2013):

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

Many of the measures that can be considered under this framework are not specifically focused at reducing air pollution, but will have an impact on air pollution and so provide a useful framework for looking at solutions. This is illustrated in Figure 2 below, where Avoid-Shift-Improve will be the *outcomes* of a range of transport *measures* and this will *impact* on transport emissions and air quality in the following three ways:

- *Reducing traffic levels* – for all or certain vehicle types will be the main impact of avoid and shift outcomes, whether it is from reducing overall travel or restricting certain types of vehicles or encouraging the uptake of sustainable transport through, for example, the provision of cycling facilities. Fewer vehicles will then produce proportionally less emissions and hence lower air pollution concentrations.
- *Improve vehicle flow* – through affecting vehicle speed, congestion levels and so on, to reduce the direct emissions from a vehicle. Avoid and shift outcomes will help reduce congestion by reducing traffic volumes. Direct measures such as traffic management and improving driver behaviour, can further reduce total vehicle emissions.
- *Improved vehicle technology* – promoting low emission vehicles, or restricting more polluting vehicles, will improve the overall emission performance of the vehicle fleet.

Figure 1: A framework to manage transport emissions and air quality



Any particular transport measure may have one or more outcomes, for example a travel mode change campaign may both lead to avoidance of trips and shifting of mode of travel. This in turn will impact by reducing traffic levels and congestion, and so reduce vehicle emissions. In considering measures there are perhaps three broad categories:

- *Managing the demand for types of travel mode and encouraging the uptake of more sustainable travel modes such as walking and cycling* – are a wide range of measures aimed at reducing trips and shift mode of travel. It covers land use planning, travel mode change campaigns, infrastructure investment and pricing measures.
- *Access control and management* – covers the more traditional measures such as vehicle restricted areas, traffic management and fleet management.
- *Promoting low emission vehicles* – this can be done through a number of mechanisms such as planning, procurement and partnership work, as well as direct access control.

Each of these groups of measures is explored below considering what outcomes and impacts they may have, and also what policy instruments are available to implement them and the potential costs of doing so.

The assessment of each policy measure is considered on the following critique questions:

Table 2 Questions for the detailed review

Specific Questions
Primary research question: *What quantifiable effect might a range of policy measures potentially have on NO_2 concentrations?* *Secondary research questions:* *What quantifiable effect might the specified policies have on perceptions or behaviours amongst the general public, specific transport user groups or other stakeholders?* *What quantifiable effect might the specified policies have on traffic flows, composition and speed?* *What quantifiable effect might the specified policies have on NO_X emissions?* *What are the unintended consequences, including effects on other pollutants and other environmental/ social effects? Are there any disproportionate impacts on particular groups of people/organisations?* *What are the contributory factors (triggers and barriers) to effective implementation of a package of measures to reduce NO_2 concentrations at both a local and national level?*

2.2 Demand management and encouragement to change mode of travel

When considering solutions to reduce the environmental impacts of transport, it is important first to appreciate what drives transport demand. Very few journeys are made for the sake of the journey alone Access to public transport facilities will be of high importance to reducing demand for cars, including the provision of buses and bus priority measures in urban areas.

2.2.1 Land use planning and development control

This group of measures includes the following from Annex 1: Strengthen air quality planning regulations.

Land use and spatial planning policy can be used to control the patterns of land use which in turn determine demand for transport. If land use planning is to be used to minimise transport's environmental impacts, including air pollution, then it must be used to create patterns of land use which reduce trip lengths and encourage journeys to be made by the most sustainable modes. Reducing the need for motorised traffic in turn reduces air pollution and noise, benefitting health (Frank *et al*, 2006). However, the impact of these polices are over the long term and are unlikely to address the immediate need to reduce emissions and therefore will not be considered further in this study. Their longer term effectiveness, however, is evident in the literature.

Development control alongside transport planning also covers the construction of infrastructure to support other policy measures e.g. cycle lanes (signage requires planning consent), provision of new multi-storey car parks, fuel storage and supply etc. These transport policy measures are considered further in this report and where they are deemed to bring air quality benefit, development control will in most cases be a required supportive enabling measure.

It is apparent that local planning authorities do consider air quality impacts in planning decisions and many have local planning guidance, the most recent of which refers to the National Planning Policy Framework (NPPF). The NPPF considers air quality (e.g. paragraph 124) during the planning process. Additional guidance is available to local authorities via the planning portal. Recently published guidance on planning and air quality impact from EPUK/IAQM strongly encourages local authorities to develop their own local low emission planning guidance to strengthen the impact planning policy can achieve in reducing emissions (EPUK/IAQM, 2014).

2.2.2 Information campaigns to encourage sustainable travel

Achieving change in travel mode choice can be an effective strategy to manage transport demand and so reduce negative environmental impacts. All measures to reduce NO_x emissions from transport require changes in travel mode choice which may come about through an incentivisation, public engagement or a regulatory scheme. Measures to provide information on alternative ways of travelling or encouraging lift-sharing can be implemented relatively quickly compared to provision of transport infrastructure, or the development and introduction of cleaner vehicles, and in many cases can be a more cost effective approach.

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

- A reduction in the number of car driver trips (down by 8%) and car driver distance (down by 5%-7%) per resident;
- The overall reduction in traffic was around 2%, and 8% in inner areas;
- Bus and other public transport trips per resident increased in two out of the three towns and by 14% overall;
- Cycle trips per resident increased by 26% overall;
- Walking trips per resident increased by 13% across the towns.

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

However there can be significant barriers to influencing travel choices and behaviours. Many of the journeys that are made are habitual and the way they are made is firmly integrated into people’s daily routines. These choices can also be influenced by values and aspirations (Goodwin & Lyons, 2010). Over 80% of journeys are under ten miles – daily commuting, shopping trips, taking children to school. People typically do not consider what alternatives exist each time they make such journeys. However, more recent research (Chatterton & Wilson, 2014) suggests more the public show more flexibility in travel choice.

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

One of the unintended consequences of demand management can be that new public transport facilities are used by passengers from other modes of public transport. For example, when the Manchester tram became operational demand was high but bus patronage fell (Senior, 2008). Also in York with the launch of their Park and Ride facilities demand was high from commuters, but the released road capacity encouraged commuters back to their cars and congestion returned to original levels (Tate, 2013). Attempting to reverse this trend could require measures to reduce the road capacity, including cycle lane provision and signal timings.

2.2.3 Communication technology and travel choice

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

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

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

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

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

2.2.4 Managing freight demand and supply

Better management to reduce the overall numbers of freight journeys can give further air quality benefits, with heavy duty diesel vehicles being a significant source of emissions in many cities. A study of UK urban freight vehicles (Allen & Browne, 2010) provided data on loading factors which ranged from 40% for local deliveries to 70% for primary inbound deliveries. This suggests there is scope for greater consolidation of urban freight activity, particularly for deliveries to small retail or catering businesses, which often have inefficient delivery patterns (DG MOVE, 2012). Transport for London (TfL) has developed an approach to reducing vehicle trips with delivery and servicing plans. These have reduced the number of deliveries by about 20% (Transport for London, 2009).

2.2.5 Shared modes and new mobility services

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

Public bicycle or bike share schemes

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

In a survey of the Vélib' bike share scheme in Paris, 46% of users reported lower private car use, 27% of long term subscribers use the bicycles for commuter trips, 13% for business trips, and 28% use

Vélib' to start or finish a public transport journey (Beroud *et al*., 2010). However bike share trips often primarily replace public transport use with one report finding only 7-13% of trips replacing car, motorbike or taxi trips (CSD, 2011) though results from the first year of operation of the Barclays Cycle Hire scheme in London (2010) showed two-thirds of trips replaced travel by car, taxi or public transport (Transport for London, 2010).

Health benefits of investing in such cycling schemes have a 2.59 multiplier in terms of reduced mortality (Wilson *et al*., 2011). It is also noted that the health benefits of cycling range from 3-14 months gained in comparison to the risk of road traffic accidents, amounting to 5-9 days lost and exposure to air pollutants, which range from 0.8 to 40 days lost (Rojas-Rueda, 2011).

As an indirect result users who have switched from cars to biking schemes have reduced the CO_2 emission in the cities and freed up road space, which providing this is not filled by suppressed demand, would result in less congestion and associated air pollutant emissions. Also it is worth noting that cycling provides accessibility to areas which have poor coverage of public transport (Transport for Greater Manchester, 2011).

Air pollution levels related to car use are one of the key drivers for the introduction of cycling schemes in city centres as can be seen in the case of Greater Manchester. On roadside locations NO_2 levels have significantly exceeded the national air quality objective of 40 µg m^{-3}. It is noted that among the options to reduce the air pollution in Manchester cycling infrastructure is considered the most cost efficient (Transport for Greater Manchester, 2011).

For trips that are longer than 1.5 km the bicycle can lose some travel time compared to the car (Inês & Ribeiro, 2014). Estimating the transportation demand and its variation causes a difficulty for urban transportation planners as it is influenced by many factors (Inês & Ribeiro, 2014). Since the introduction of the bike share programme in London, only 2% of journeys by car have been replaced by bikes, which is considered to be due to the large spatial area of the city (Fishman *et al,* 2014).

Although implementation of bicycle schemes and bicycle highways is beneficial for urban areas, capital costs associated with such measures can be high, and for example in the case of London have been in the range of £79 million (GLA Transport Committee, 2010).

The evidence suggests that the implementation of measures to increase cycling (and reduce car use) should be accompanied with other measures to reduce road capacity to sustain gains in more highly polluted areas and prevent back fill of the road space with suppressed car demand.

Car-sharing or car clubs

In a car-share scheme, members typically pay an annual fee and then pay per hour of use to access a car. In most schemes, vehicles are located at designated parking spaces and are booked and paid for in advance via the internet, but some so-called "free-floating" schemes (such as Daimler's Car2Go and BMW's DriveNow) allow the user to pick up a car without pre-booking and drop it off wherever they wish. Members of car-share schemes have lower average annual mileages and use a much greater range of other modes than traditional car owners (Carplus, 2013). Car share vehicles also have 20% lower CO_2 emissions than average private cars (Carplus, 2013); NO_x emissions were not compared. The more intensive usage of car-share vehicles means low emission technologies are more cost-effective for companies running the scheme and they often promote electric and other low emission city car technologies (Schipple & Puhme, 2012).

2.2.6 Pricing

The classical economics approach to influencing travel demand and behaviours is through pricing, with the aim of setting transport price signals to achieve an optimal level of mobility for society. They should also encourage people to choose modes of travel which minimise the negative social and environmental impacts of our travel, such as air pollution. Such impacts are known as 'externalities', and in order for transport prices to lead to optimal choices, the costs of these externalities must be internalised into the prices people pay, sometimes known as the "polluter-pays" principle.

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

- Fuel duty and the resulting differentials
- Vehicle excise duty
- Company car tax
- Capital allowances

However, vehicle purchasers, particularly commercial operators, report that they need to be sure that these policies will not change during their ownership of the vehicle adversely affecting their expected payback period for investing in cleaner technology. For example CNG and LNG for road use currently benefit from lower fuel duty than diesel which may make switching to gas engines attractive for road hauliers. However a clear message from recent research into barriers to uptake of low emissions technologies for heavy duty vehicles was that this differential needs to be guaranteed for at least 10 years, particularly given that operators may have to invest in their own refuelling infrastructure in order to switch to gas (Ricardo-AEA, 2013).

At the local level pricing mechanisms can be applied by through parking fees, as discussed in section 2.3.3. Similarly local road pricing schemes can be used to differentiate between different types of vehicles, for example the clean vehicle exemptions in the London Congestion Charge. In the case of the London Congestion Charge scheme the direct impact of the exemption on air quality is hard to separate from other impacts, but it is clear that it has had an impact on the vehicle fleet with a much fast growth in hybrid vehicles than other areas in the UK and Europe (Transport for London, 2010).

2.3 Access control and management

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

- Vehicle restricted areas
- Low emission zones
- Parking management
- Traffic management

2.3.1 Vehicle restricted areas

Access control is widely used in cities across Europe to restrict vehicle activity, particularly in areas with high levels of pedestrians for road safety purposes. It covers a wide range of measures including time restrictions, size and weight restrictions and controls related to vehicle emissions. It is used to avoid inappropriate traffic, such as articulated lorries accessing narrow urban streets, and unnecessary trips, and is generally implemented for environmental or congestion reasons. Most schemes are targeted at freight and freight/private cars, rather than solely at private cars (DG TREN, 2010). The targeting of heavier vehicles reflects their proportionally higher environmental impact.

Examples in the UK include York's Footstreet scheme, Nottingham's Clear Zone and Bath's Bus Priority Gate. All these schemes have been designed to reduce traffic levels and the associated safety and environmental impacts, and form part of wider economic development and regeneration work. However, the geographic scale of such measures is typically quite small and often isolated to a town centre streets.

2.3.2 Low Emission Zones

A specific type of vehicle restricted area is the Low Emission Zone (LEZ) where vehicles not meeting specific emission criteria are restricted. The restrictions can be linked to specific vehicle types and related to Euro emission standards, vehicle age or technology. They can be in the form of an outright ban or through variable charging, and in many cases are aimed at heavy duty vehicles as these have the highest emission rates per vehicle. The most well know example in the UK is the London Low

Emission Zone, but there are a number of other major schemes across Europe including Berlin, Amsterdam and Stockholm.

2.3.3 Parking management

The control of the supply and cost of parking can be used to manage transport demand and have a direct impact on traffic levels. Instead of allowing unregulated, free parking, many argue that prices should be set to limit demand to about 85% of maximum occupancy (Shoup, 2005). Inefficient and poor parking controls generate additional traffic and congestion, with as much as 50% of traffic congestion can be caused by drivers cruising around in search of a cheaper parking space (ITDP, 2011). A 2012 RAC Foundation report on UK parking policy also recognised the impact of inefficient parking on congestion and vehicle emissions. The report called for better provision of information to ensure efficient vehicle parking and a more consistent approach to pricing to cover both the direct costs of parking and as a management tool to manage congestion (RAC Foundation, 2012b).

It can also be used to encourage less polluting vehicles through priority/restricted parking for low emission vehicles or reduced parking pricing for low emission vehicles. Milton Keynes has introduced a ‘green’ parking permit for drivers of vehicles which are in tax band A (CO_2 emissions of 100g/km or less). This gives a discount when using standard rate parking spaces. In Edinburgh, residents’ parking permits are graded according to engine size or CO_2 emissions levels, with those in the highest bands paying over six times more than those in the lowest. Richmond offers free residents parking permits to owners of tax band A vehicles and York has also introduced low emission vehicle parking permits giving up to 50% discount on residents’ parking. In Europe, Bremen has a system of environmental loading points for low emission delivery vehicles and Madrid is currently studying the possibility of a parking charge differential of 20% in different areas depending on parking demand and the level of NOx emissions.

In most cases the main assessment has been on the impact on parking revenues with the current fleet rather than the likely change to that fleet and emissions benefits, but in general impact will depend on the scale of the charges or nature of restrictions applied. Also any such policies can be undermined by availability of private uncontrolled private off-street parking (RAC Foundation, 2012b).

2.3.4 Traffic management

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

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

Road space rationing is a travel demand management strategy aimed at reducing the negative externalities generated by peak urban travel demand in excess of available supply or road capacity, through artificially restricting demand. In 1989, the government of Mexico City introduced a programme, banning approximately 460,000 drivers from using their vehicles one day per week on the basis of the last digit of the vehicle’s license plate (Davies, 2008). Compliance was considered to be near universal (vehicles violating easy to spot). However, the average daily pollution levels during 1986–2005 showed no apparent improvement in air quality (Davies, 2008). Similar road space schemes were in place in Paris and Athens during high pollution episode events in March 2014. On the 17th March 2014, only motorists with odd-numbered number plates and low emission vehicles were allowed to drive into central Paris. The resultant lower traffic levels and a change in weather conditions significantly improved the smog. Road space rationing has been used to address short term (a few days) episodes of high pollution with varying degrees of effectiveness.

2.4 Promoting low emission and alternative fuel vehicles

The primary objective of promoting a switch to low emission vehicles is the reduction of carbon and air pollutant emissions from transport. However, it does not have additional benefits such as congestion reduction or increased levels of physical activity that are generated by 'avoid' and 'shift type measures. New low emission technologies such as battery electrics and hybrids are becoming increasingly available. It is also worth noting that vehicles that incorporate regenerative braking, such as electric and hybrid vehicles, can reduce non-exhaust particulate emissions relating to tyre and brake wear, further reducing air pollution levels (AEA/TNO/CE Delft, 2012).

2.4.1 Incentivising low emission vehicles

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

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

2.4.2 Vehicle scrappage

One of the most targeted ways of controlling older, high-emitting vehicles is to eliminate them from the fleet altogether through mandatory or heavily subsidised voluntary scrappage. HDV scrappage schemes typically address conventional pollutant emissions e.g. PM_{10} only, while in many countries light duty scrappage schemes have targeted both air pollutants and CO_2. In many cases scrappage schemes are successful in reducing emissions and stimulating economic growth. This is achieved as scrappage subsidies are offered on the condition that the vehicle owner simultaneously purchases a new (or nearly new) vehicle. The additional demand created in an aggressive scrappage scheme can help ensure demand for new vehicles as part of the transition to a newer, more stringent national emission standard. However scrappage schemes are perceived as expensive and are generally cost-effective only in the short term.

2.4.3 Vehicle retrofit

Vehicle retrofit consists of the implementation of an on-board device that allows vehicles with a determinate emission standard (i.e. Euro) to comply with more stringent standards by reducing the emission of pollutants through technical measures. Retrofit measures are usually either Exhaust Gas Recirculation (EGR) or Selective Catalytic Reduction and Urea technology (SCR and Urea) measures. Vehicle retrofitting has been gradually implemented in the UK over recent years. Grants have been awarded in the UK (from the Energy Savings Trust and Transport Energy Clean-Up Programme for retrofitting particulate filters and devices (EGR, SCR) to reduce NO_x emissions. In London, more than 1000 buses have been retrofitted in a Transport for London project with equipment to reduce NO_x emissions. This was in response to calls to retrofit the vehicle fleet in the UK to meet Euro 5 exhaust emission standards. Priority of retrofitting was given to bus routes passing through areas of high NOx concentrations (Air quality news, 2014). The Mayor of London and Transport for London recently announced that they are to expand London's bus retrofit programme with a further 400 vehicles, bringing the total number of buses fitted with a SCR system up to 1,800 (TfL, 2015).

2.4.4 Eco-driver training

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

2.4.5 Procurement policies

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

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

2.5 Results from Screening Activity

To identify measures with the most potential to improve air quality an assessment of each measure was undertaken based on either evidence from the literature review where available (either direct e.g. impact on NO_2 or indirect e.g. traffic flows) or from professional judgement within Ricardo Energy & Environment. The measures with the most potential are explored in further detail in the literature review in the following sections. The assessment was against the following criteria:

1. Effective – has the measure the potential to reduce NO_2 (scale 1-4 with 1=low,4-high)
2. Nationally applicable – has the measure the potential to be implemented on a national scale rather than the local scale and hence reduce emissions more widely (scale 1-3, 1=no, 2= maybe, 3=yes)
3. Deliverable – Are systems in place e.g. legislation or can systems be put in place to enable the measure to be implemented (scale 1-3, 1=no, 2= maybe, 3=yes)
4. Affordable - how expensive is the measure in comparison to other available measure. (scale 1-3, 1=high, 2= medium, 3=low)
5. Achievable - can the measure be successfully implemented e.g. is it acceptable to the community (scale 1-3, 1=no, 2= maybe, 3=yes)
6. Timescale for impact – How quickly will the impact be realised following measure implementation (scale 1-4, 1=slow, 4 = immediate)
7. Impact on other pollutants – Would the measure impact other pollutant levels e.g. PM, GHGs (scale 1-3, 1=no, 2= maybe, 3=yes)
8. Likely uptake – how many people are likely to uptake the measure (scale 1-3, 1=low uptake, 3=high uptake)
9. Positive wider impact– what is the impact of any positive wider impacts and unintended consequences e.g on noise, social inequality, economic issues, road safety, journey times, production of waste (scale 1-3, 1=low,3=high)
10. Negative wider impact – what is the impact of any negative wider impacts (scale -3 to -1, -3= high, -1 = low)

The results of the assessment are presented in Table 3 below. We doubled the weighting for the scores in `effectiveness' and `timescale for impact' to reflect that these were the key criteria to find measures that were effective in as short a time as possible.

It should be noted that as the measures were assessed on the *potential* for these measures and it is accepted that the scores vary considerably depending on how these measures are designed and implemented. Pricing policy levers look to be the most attractive to reduce NOx emissions and therefore will be considered in more detail in the next chapter of this report. In addition, Low Emission Zones also score highly (on the basis that vehicle standards similar to those proposed in the Ultra-Low Emission Zone in London are included and that the Euro 6 standard real world driving delivers as expected). It is clear from the literature that a package of measures can be more effective in improving air quality compared to single measures, for example a Low Emission Zone can be implemented alongside complementary policies such as vehicle retrofitting, vehicle scrappage schemes, and grant funding to accelerate the uptake of low emission vehicles and fuels. As these measures were identified in the screening assessment as the most likely to be effective they are reviewed in further detail in the following sections of the report.

Table 3: Assessment for measures potential.

Literature review screening criteria	Effective	Nationally applicable	Deliverable	Affordable	Achievable	Timescale for impact	Impact on other pollutants	Likely uptake	Positive wider impact	Negative wider impact	Total score
Additional planning policy	1	3	3	3	2	1	1	1	1	-1	**17**
Information campaigns to encourage sustainable travel	1	2	3	3	3	3	3	1	1	-2	**22**
IT and travel behaviour	1	3	3	3	3	3	1	1	1	-1	**22**
Freight management	2	1	2	3	3	3	2	1	1	-1	**22**
Shared modes	1	1	3	3	3	2	2	1	3	-1	**27**
Pricing	4	3	3	3	3		3	3	3	-3	**34**
Vehicle restricted access	3	1	3	3	3	3	2	1	2	-1	**26**
Low Emission Zones	4	3	3	3	3	3	3	3	3	-2	**33**
Parking/Traffic management	2	1	1	3	3	3	2	1	1	-2	**20**
Vehicle retrofit	3	3	3	2	3	3	3	2	2	-1	**29**
Vehicle scrappage	4	3	3	2	3	4	2	1	2	-2	**30**
Incentivising low emission fuel/ vehicles	4	3	3	2	3	2	3	3	2	-1	**30**
Eco Driver training	2	1	1	3	3	2	3	2	2	-1	**22**
Procurement	2	3	3	3	3	1	2	1	1	-1	**21**

Transport activity is driven by a wide range of needs and choices, and has a range of impacts including congestion, air pollution, carbon emissions, and accidents. Consequently, as demonstrated in Annex 1, there are a wide range of measures and actions that can be taken to influence travel patterns, mode choices and technologies in order to reduce these impacts. Many of these measures are not primarily designed to reduce emissions and improve air quality, rather being focused on congestion reduction, but will often help reduce emissions and can be enhanced to have greater air quality benefits.

The quantity of evidence on the air quality impacts and costs of these measures is low for several reasons:

- They have not been primarily designed to improve air quality and so this has not been assessed directly;
- They are often very locally specific so it is difficult to draw clear transferable results;
- There are still significant uncertainties with regards to real world vehicle emissions performance in relation to such measures.

Evidence on uptake responses to specific measures is also still developing. The rapid evidence review flagged up numerous technical and non-technical measures that have been implemented in cities in Europe and around the world, and whose efficiency in bringing about behavioural changes or emissions abatement has been contrasted. In many cases these efforts have not been sufficient or have not achieved the desired outcomes, as evidenced by the continuous non-attainment of various air quality management zones with such limit values. The analysis of the different abatement measures suggests that the most cost-effective measures, when considered in terms of delivering air quality objectives are those that specifically target air quality.

3 Pricing Package of Measures

Box 1: Key findings: Pricing

- Some pricing measures have been demonstrated to be highly effective. Use of taxation is one of the most cost effective measures as the implementation is typically straightforward in an existing system. However, the literature is clear that any pricing mechanism scheme, whether it is a national tax duty or local road toll, should be designed with great care as the unintended consequences can be detrimental to air quality and have social inequality impacts.
- The literature suggests that policies should include the consideration a number of measures packaged together to achieve the best outcome for the reduction in NOx

The literature review showed that the use of taxation instruments by policy makers is an effective tool to drive the preferences of consumers towards specific choices. The review considered general taxation and direct costs separately. The commonly-cited example in the literature of the impact of pricing mechanisms in the European context is the recent dieselisation of the vehicle fleets in many countries, linked to the application of fuel taxes which intended to lower CO_2 emissions from vehicles, which in turn conditioned fuel consumption. The effect of company cars on UK dieselisation is reported separately.

This section considers price mechanisms in terms of:

- General Taxation
- UK Company Cars
- Direct Costs

3.1 General Taxation of road vehicles

Box 2: Key findings: General Taxation of road vehicles

- The literature review showed that the use of taxation instruments by policy makers is an effective tool to drive the preferences of consumers towards specific choices.
- A well-documented example, in the European context, is the recent increase in vehicles with lower CO_2 emissions in many countries to support climate change policy, linked to the application of taxes.
- In general, taxation is considered to be a very cost effective policy instrument. The administrative simplicity of applying taxes is their main advantage over other measures, due to the fact that a tax collection system is already in place.
- Examples of this could include taxing vehicles differently according to their fuel type, engine capacity, size, etc. or applying different rates to diesel and petrol.
- Many studies have considered the relationship between vehicle taxation, use of public transport and congestion, with an increase in vehicle or fuel taxes leading to less congestion and distances travelled, and increase in the use of public transport particularly in urban locations.
- Other studies have highlighted that use of taxation to manage emissions is a socially inequitable solution, with those in socially deprived or rural areas particularly disadvantaged.

The road transport sector is generally regulated by using fiscal instruments that act either on vehicle/fuel purchase or during the vehicle use phase. Most of these regulations have an impact on fleet transitions which could affect air quality in different ways. Fiscal instruments that are considered relevant for policy making include

(i) Vehicle registration taxes (VRT) (Vehicle Excise Duty in the UK),

(ii) Duty/fuel excise taxes and

(iii) Purchase taxes

Other taxation schemes may consider contributions on trips or travelled distances (Santos *et al.*, 2010).

3.1.1 Impacts of the Measure on NO_2 and Potential Effectiveness

A study focusing on the Republic of Ireland highlighted that the current focus of policy action concentrating on car taxation to drive decarbonisation of fleets reduced NO_x emissions (Leinert *et al.*, 2013). Particularly, this study demonstrated that an adjusted vehicle registration tax rate (VRT) that is tailored to the characteristics of the vehicle fleet can bring about reductions in NO_x emissions (approximately 36%) as well as fuel savings. Fu and Kelly (2012) estimated that a 5% increase in fuel price would lead to a CO_2 emission reduction of 1.75% in Ireland but this would lead to a minor increase in NOx and PM emissions.

A study in China focusing on scenarios by 2050 estimated that the annual NO_x emissions would decrease by 4.6% under a 10% tax rate, as well as by 24.3% under a 100% fuel tax (Mao *et al.,* 2012). A reduction in NO_x emissions was echoed by Barnett & Knibbs, (2014) who stated that in Australia, 'higher diesel prices were associated with statistically significant short-term reductions in NO_x (up to 30%) and CO (up to 70%).

The literature shows that the use of taxation to encourage the uptake of vehicles with lower CO_2 emissions can be considered as very effective.

3.1.2 Wider Impacts and Unintended Consequences

General taxation schemes on vehicles have a direct effect in purchase and vehicle use. One response to policies to increase purchase tax is that fewer cars are purchased overall, mainly as a result of the higher average car price. Brand *et al.,* (2013) found in the UK that a 6% decrease in car sales from a purchase tax which was graded by fuel type and CO_2. This then reduces the number of vehicles on the road and reduces traffic emissions and congestion. An example in Belgium revealed that finding an optimised vehicle ownership tax for petrol vehicles (21%) and for diesel vehicles (15%) reduced the general traffic flows by 0.06% and 0.03% for peak times, and 0.14% and 0.20% for off-peak times respectively (Mayeres & Proost, 2001).

Fuel taxes are usually recognised as a limiting factor for unnecessary fuel consumption and that its abolition could increase emissions (Sterner *et al,* 2007). However, the studies on the effects of fuel taxes on emissions and on road traffic variables are limited. A study focusing on the United States by Welch & Mishra (2014) demonstrated that a $0.1123 increase to existing fuel tax measures in Maryland, would result in a 0.51% and 0.66% decrease in daily vehicle miles travelled and vehicle hours respectively (Welch & Mishra, 2014).

Higher fuel prices may also encourage more people to use public transport, although this may not be the case in more rural areas where it may be difficult to use public transport due to a lack of networks or low service frequency (Cavalcanti *et al.,* 2012; Fujisaki, 2014). It is also thought that in the absence of fuel taxes, fuel demand in Europe would be much higher than it is today (Sterner, 2007). Further response behaviour is that consumers in China tend to choose cleaner technologies, those powered by electricity and natural gas, when petrol and diesel consumption is taxed (Mao *et al.,* 2012). High fuel prices also encourage energy efficiency through the development of more economical driving habits (Cavalcanti *et al.,* 2012). In Europe, fuel taxes induce consumers to purchase more fuel-efficient vehicles which will, in the longer term, lead to more fuel-efficient vehicles being produced and may also reduce travelled mileage (Clerides & Zachariadis, 2008).

In the case of purchase taxes, these tend to produce a reduction in new car uptake which in turn may induce an over-consumption of older and more polluting vehicles. Higher taxes on new vehicles need to be matched by higher taxes on second-hand vehicles in order to reduce shifting purchase behaviour towards older and more polluting vehicles (Santos *et al*., 2010).

Current fuel taxes are likely to bring about a fuel switch to diesel in the UK as there are polices to incentivise the uptake of diesel to support climate change policy (Rogan et al., 2011; Fu and Kelly, 2012; Brand *et al.*, 2013) with resultant changes to the fleet. Furthermore, where petrol cars were purchased, these tended to have smaller engines (Rogan *et al*., 2011). In the Republic of Ireland, the implementation of fuel taxes, vehicle registration taxes, and carbon motor tax projected a reduction in the demand for petrol cars and increased the demand for diesel cars (Fu and Kelly, 2012). For example, in 2030 the effects of a 5% increase in fuel excise tax in Ireland were predicted as follows: the numbers of private cars of diesel, small size (PCDS), private cars of diesel, medium size (PCDM) will increase by 7.44% and 1.90%, respectively, and private cars of diesel, big size (PCDB) will decrease by 5.90%, and the changes of private cars of petrol, small sizes (PCGS), private cars of petrol, medium sizes (PCGM) and private cars of gasoline, big sizes (PCGB) will be -3.1%, -9.1% and -16.52% respectively (Fu and Kelly, 2012).

A study aimed to examine the effect of a 10% fuel price increase in Costa Rica found that the effect of such a price increase through direct spending on petrol would be progressive. It also highlighted that households in the highest socioeconomic strata would be the most affected, while the effect of the price increase through spending on diesel (either direct spending or indirect via bus transportation) would be regressive: households in the lower and middle strata would be affected due to their heavy reliance on bus transportation.

The study published by Welch & Mishra (2014) has shown that the impact of fuel tax was detrimental to travellers' welfare, particularly for lower income groups. For instance, a change in per capita annual traveller's welfare, for people earning less than $29,000 and between $100,000 and $149,999 per annum were respectively shown to be -$47.25 and -$41.03. The conclusions of this study highlights that the use of fuel taxation might constitute a non-equitable solution.

3.1.3 Implementation Success Criteria

Direct taxation based on a vehicle's emissions can be a straightforward way to promote low emitting vehicles. For example both Germany and Switzerland levy differentiated taxes on Heavy Duty Vehicles based on their certified emission standard. In Switzerland a performance related tax is levied on all HDVs travelling on public roads. The fee is calculated on the total weight of the vehicle, the number of miles driven and the tailpipe emission standard.

Most of the work related with fiscal instruments as policy options for the abatement of emissions concentrate on impacts on greenhouse gases rather than nitrogen oxides. Historically, policies directed to the decarbonisation of vehicle fleets have not been well-aligned with those intended to tackle airborne emissions (Santos et al., 2010). It is therefore important to harmonise policy making approaches by aiming to implement fiscal instruments that act on greenhouse gases and nitrogen oxides in parallel.

The successful application of fuel taxes is subject to a significant degree of practical constraints. In the UK, Brand *et al*. comment that fuel duty rates for road transport fuels are currently relatively high (£0.58/l) so there is little room for manoeuvre in terms of public and political acceptance (Brand *et al.,* 2013). An additional concern is the fact that policies are normally shaped by economic interests and the higher the dependence on private motorisation among the electorate, the more difficult it is politically to raise fuel taxes (Sterner, 2007). This political feasibility is echoed in other studies (De Borger & Mayeres, 2007; Clerides & Zachariadis, 2008; Yan & Crookes, 2009; Barnett & Knibbs, 2014).

In general, within the literature, taxation is considered to be a cost effective policy instrument. The administrative simplicity of applying taxes is their main advantage over other measures, due to the fact that a tax collection system is already in place (Santos *et al*., 2010). According to Silva-Send *et al*., (2013), in the United States the implementation of a rise in fuel tax is close to zero net cost and a fuel tax is the lowest cost way of reducing fuel use, with a total cumulative discounted cost between $0.7 and $1.7 billion/year (Karplus *et al.,* 2013). Moreover, Parry (2008) estimated that in the United States the optimal (second-best) diesel fuel tax at $1.12 per gallon increased public revenue by $1.34 billion per annum. The aforementioned highlights the great potential for welfare gains from fuel taxes (Parry, 2008; Proost *et al.,* 2009). Additionally, the fact of limiting the use of vehicles through the taxation of registration, fuels or purchases has a major benefit in the form of a reduction of accident externalities and congestion (Proost *et al.,* 2009).

The evidence from the literature is that the application of taxes is highly conditioned by their acceptance by the public. A study in Norway found that there was higher public acceptability of an increase in fuel tax if this was accompanied by an increase in environmental quality and a reduction in congestion (Kallbekken *et al*., 2013). In addition, in Norway fuel taxes are perceived as more effective air pollution control instruments than road pricing and parking charges. In the UK, evidence indicates the public is generally suspicious of green taxes because these are thought an excuse for the government to raise revenue (Clerides & Zachariadis, 2008). In the case of Brazil, tax reductions have been applied to promote use of alternative fuels such as bioethanol and these have been gradually accepted by society (Cavalcanti *et al.,* 2012). Schade & Schlag (2002) determined from a public acceptability survey of 952 motorists from four European cities that 'social norm[2]', 'personal outcome expectations[3]' and the 'perceived effectiveness[4]' are positively related with the acceptability of fuel taxes/pricing strategies.

Generally, public acceptability of taxing is low and there is much opposition to adopting tax-related measures, which usually do not pass without political cost to decision makers (Raux & Marlot, 2005; Sterner, 2012). A study in Australia reflected that tax increases for vehicles rarely garner public support and any Australian politician that recommends increasing the price of fuel is likely to be voted out (Barnett & Knibbs, 2014). An example of the negative effects of tax increases on public opinion is reflected by constant demonstrations and protesting from motorists, truckers, farmers and other large users of motor fuels in countries like Spain & Poland (Hickson, 2006).

2 'More precisely, social norms refer to the respondent's assumption about whether his significant other would think that he should accept the strategy.'

3 Personal outcome expectations = equity 'Here, equity primarily refers to the distribution of costs and benefits'

4 If someone recognises traffic problems and their consequences (problem perception), and identifies at least in part the aims of changing these problems (reducing traffic congestion, declining environmental damage, etc.), he or she has to answer the crucial question, of whether the proposed measures are of appropriate effectiveness and efficiency.

3.2 UK Company Car Taxation

Box 3: Key findings: UK Company Car Taxation

- The Company car market is responsible for about 50% of new cars on UK roads.
- The current tax landscape strongly incentivises the selection of vehicles with lower like-for-like CO_2 g/km rating to address climate change policy. Some studies claim that the outcome has been an increase in diesel vehicles as they have a significantly lower CO_2 emission per km travelled compared to petrol fuelled cars.
- The literature shows that the taxation of company cars to reduce road vehicle CO_2 emissions has been very effective with a decrease in emissions evident across Europe.
- A key unintended consequence has been a rise in NOx emissions, as many vehicles (diesel) with lower CO_2 emissions do not have a corresponding low NO_x emission, particularly under real world driving conditions.
- Any changes to company car taxation may have an impact on use of public transport and congestion levels.

3.2.1 Impacts of the Measure on NO_2 and Potential Effectiveness

Policy on company car taxation has been focused in many countries on CO_2 rather than NO_x emissions as measures to address the company car sales market has the potential to influence road vehicle emissions. New car sales in the UK are split 50:50 between company (business and fleet) and private sales. Between January and April 2014 new car sales were: 9.4% business, 40.9% fleet and 49.7% to the private market respectively (SMMT, 2014a). The company car market is therefore responsible for every other new car on UK roads. This split has been relatively stable in the UK and across the EU since 2005 (Naess-Schmidt & Winiarczyk, 2010). The combination of market demands and tax structure means:

- Private car sales dominate the Mini (79.3%), Supermini (66.3%), Specialist sports (67.1%) and Dual purpose (67.2%) market segments
- Company car sales dominate the larger Lower medium (56.4%), Upper medium (71.9%), Executive (60.5%), Luxury saloon (50.4%) and Multi-Purpose Vehicle (MPV, 64.8%) market segments.

Diesel car sales just exceed petrol, with the share of alternatively fuelled (AFV - hybrid is the dominant category) at a low level but the demand is rising fast. The 2014 figures to October were diesel 49.9%, petrol 49.3% and AFV 2.0% (SMMT, 2014b). This split in the car market gives rise to the potential of a taxation system to influence overall emissions from this section of the fleet.

Vehicle tax includes Vehicle Excise Duty (VED). This is due annually and is now based on the registered CO_2 performance, rather than engine size as previously (vehicles registered before 1st March 2001). VED is payable by both Company and Private car owners. No VED is due in the first year (April 2014 – 2015) if a vehicle is registered to emit less than 130grams/ km of CO_2. Conversely VED for cars that emit a lot of CO_2 per km are elevated in the first year, before falling back to a standard rate for a particular band (EST, 2014) which are again scaled according to a vehicles official CO_2 performance.

Company Car Tax (CCT) is a "Benefit in Kind" (BIK) tax, calculated by applying the appropriate rate to the list price value of the car. The BIK rates for 2014/15 are listed in Table 4. The list price multiplied by the appropriate rate is adjusted by HMRC to what the car is worth to the employee for that tax year, the "Benefit in Kind". This is then added to their salary and they will pay 20 per cent or 40 per cent tax on the amount, depending on their tax bracket. Since 2002, CCT has been connected to CO_2 emissions in order to provide a financial incentive for company car drivers to adopt lower CO_2 emission vehicles, and encourage manufactures to improve efficiency. The 2002 reforms also removed the business miles element from the calculation, which could have incentivised company car drivers to drive further. There is still a diesel supplement, adding 3% to the '% of list price' if the car runs solely on diesel. The Diesel supplement was due to be abolished from 6 April 2016 (Zenith, 2014). In addition businesses are responsible for making additional National Insurance Contributions (NIC) on company cars based on the BIK rate. This tax landscape strongly incentivises employees and employers to select cars and fleets of cars with low CO_2 ratings. As illustrated by EST (2014), an employer would more than halve its NICs expenditure by encouraging employees to select a fuel efficient Ford Mondeo Edge (1.6 TDCi, 114 g/km) than a more powerful comparator e.g. Ford Mondeo Titanium S Sport (2.0l, 179 g/km).

Table 4 Company Car Benefit (BIK) rates 2014/15

CO_2 g/km	0	1-75	76-94	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175	180	185	190	195	200	205	210
% of list price	0	5	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35

For the similar engine size, diesel vehicles have a significantly lower like-for-like CO_2 g/km rating, when compared to petrol fuelled cars. Diesel car sales for example, exceeded 85% of a large company car leasing business in 2012 (Zenith, 2012). It has also been shown that diesel cars are, on average, driven further than petrol cars (11,540 miles compared to 7,350 miles respectively, National Travel Survey, 2010). Therefore whilst sales of new diesel and petrol cars are 50:50, diesel cars form a larger share of the operational fleet (vehicle kilometres driven). Some businesses operate diesel-only policies, to ensure drivers chose a more CO_2 efficient, less costly vehicles (EST, 2014). The ‘dieselisation’ of particularly the company car fleet has a significant effect on air quality, not just in the short-term, but also the long-term as it feeds the second-hand market three or more years down the line.

It is clear from the literature and vehicles sales data that company car taxation has been very successful in increasing the uptake of vehicles with lower CO_2 emissions as intended. The unintended consequences of this on NO_2 concentrations are addressed in Section 3.2.2 below.

3.2.2 Wider Impacts and Unintended Consequences

The on-road NO_x performance of diesel cars has not fallen in-line with the standards, as expected. Therefore the delivery of environmental benefits from this tax structure has been severely reduced. With the vehicle emission standard limits for petrol and diesel vehicles converging ever closer, with only small differences between the permitted g/km of air quality pollutants in legislated test conditions now in-place (Euro 6/VI), the case for differentiating and imposing a (small) ‘diesel supplement’ for example based on official figures becomes negligible. It is however now widely recognised in the literature that in normal, on-road driving diesel cars are routinely emitting NO_x at rates many times those specified in the standards (Carslaw and Rhys-Tyler, 2013).

3.2.3 Implementation Success Criteria

De Borger & Wuyts (2011) considered the influence of company car taxation on mode of travel and peak hour congestion. In this European study it was found that those with company cars used them for commuting, rather than public transport, and therefore added to congestion. It was found that in countries that provide large implicit subsidies to company cars, eliminating the preferential tax treatment of company cars may be an imperfect but quite effective substitute for currently unavailable congestion tolls. In the UK, data from HMRC (2006) showed that the change in UK company car tax policy to encourage more environmentally friendly cars by making the tax level a function of the amount of CO_2 emitted and the type of fuel used, the result was an overall increase in the value of personal use. As a result, annual business miles driven decreased by about 300–400 million miles. This reduction resulted from a change in travel mode choice on the part of drivers. It did not represent a reduction in the number of company cars (Shiftan *et al.,* 2012).

3.3 Road user charging

Box 4: Key findings: Road user charging and controls

- The effectiveness of road user charging is related to the size of the zone, but they tend to result in lower vehicle km and therefore emissions are lower.
- Cordon or road pricing need to be carefully designed to prevent vehicle redistribution and the pollution being displaced.
- Complex charges are difficult to comprehend by the public and there is public concern about the use of such revenue.
- Benefits of road user charging reported in the literature relied on the revenues being transferred to improving transport schemes particularly public transport. However, there was much discussion in numerous papers on the potential impact on social inequality.

3.3.1 Impacts of the Measure on NO_2 and Potential Effectiveness

The most popular forms of road pricing measures include Cordon Charge Schemes, Road User Charge (RUC) Schemes, Load Factor Control (LFC) Schemes and Toll Charge Schemes.

3.3.1.1 Cordon Charge

The London Congestion Zone Charge (CCZ) was introduced across a 21 km^2 area of central London on 17th February 2003 (stage 1). The CCZ was later expanded to 35 km^2 in February 2007 following the inclusion of the “western extension” until January 2011. Euro IV+ standards were implemented in January 2012 (stage 2).

Beevers & Carslaw (2005) reported a 15% decrease in vehicle km within the London Congestion Charging Zone (CZZ) two years after its implementation, resulting in a 12% reduction in NO_x emissions. However, emissions on the inner ring road had increased by 1.5%, as some traffic was redistributed across the network. The average NO_x concentrations recorded at multiple background monitoring stations within the CCZ and at its boundary showed a reduction of 8.4% and 3.7%, respectively, two years after the implementation of CCZ (Atkinson *et al,* 2009). However, the NO_2 concentrations recorded at multiple background monitoring stations at the boundary and within the CCZ unexpectedly rose by 7% and 1.3%, respectively (Atkinson *et al,* 2009). Two possible explanations were proposed. First, these changes were not attributable to the Congestion Charge Scheme (CCS) but to the other traffic management actions that acted beyond the CCZ or secondly, the CCS and other traffic management changes within the zone led to temporal changes in background pollutant concentrations that extended beyond the CCZ boundary.

3.3.1.2 Road User Charge

A Road User Charge scheme is the use of discriminatory pricing, which provides a means for matching demand to capacity in a particular location and at a given time of day, more precisely than under a single or tiered pricing system e.g. the charge for road use would be higher during peak hours and on congested routes. Discriminatory road pricing is a means to reconcile a charging mechanism aimed at regulating demand with the social objective of avoiding exclusion of low-income motorists from access to employment, shops, and other facilities (Metz, 2005).

Steininger *et al* (2007) provides an evaluation of an exclusively urban and a variety of urban-rural gradient Road User Charging schemes across the Austrian road network. An urban Road User Charge (RUC) of €0.05 per km nationally resulted in a 1.6% reduction of NO_x emissions (4.6% increase in public transport use and 5.1% decrease in distance travelled via private transport) (Steininger *et al,* 2007). If implemented across the entire Austrian network, it is estimated that the scheme would result in a 2% reduction of NO_x emissions (6.3% increase in public transport use and 6.5% decrease in distance travelled via private transport) (Steininger *et al,* 2007).

A ‘Smart RUC’ behavioural experiment, consisting of 35 anonymous and randomly selected users in the Belgium City of Leuven, used “on-board units” to relay travel information to a main server from which a toll may be allocated dependent on vehicle class, time of day and road type. For instance, a low vehicle class paid €0.0146 and €0.0163 per km on motorways off-peak and during peak times, whereas for local roads the prices rose from €0.0178 to €0.0347 dependant on the time of day (Maerivoet *et al*, 2012). Participant motorway, secondary and local road usage were correspondingly recorded at 54%, 24% and 22% prior to the trial phase, and respectively changed to 58%, 20% and 22% and concluding that some drivers moved to motorways during off peak hours which was the least cost of travel (Maerivoet *et al*, 2012). However, this change was not significant and in a third project evaluation phase 75% of drivers reverted to their original driving patterns when the charging scheme ended. This would imply that 'Smart RUC' measures may have limited potential to alter driver behaviour and should be used with care, optimally accompanied with other measures.

3.3.1.3 Freight Load Factor Control (LFC)

Pollution emissions are higher from vehicles carrying high weight loads. This measure aims to reduce emissions by charging vehicle owners according to the load weight. In a simulation of the consequences from distance-based road pricing for all agents of the supply chain in Osaka City, Japan, Teo *et al* (2014) found that a distance-based pricing scheme targeted would decrease carrier profit by 60%, and respectively produce a 25%, 20% and 12% increase in the number of trucks used, travel distances and NO_x emissions, respectively as carriers use more short distance links with lower speed limits. However, if complemented by a LFC scheme, the measure incentivised carriers to meet load factor through a wavering of charges. The carrier profits were estimated to increase by 140% and NO_x emissions would decrease by 20% (Teo *et al*., 2014). Similar findings have been reported in simulations in a North American setting (Holguín-Veras 2008, Holguín-Veras 2010).

3.3.1.4 Road Tolls

Intercity Tolls

The 'M6 Toll' was opened in December 2003 to alleviate congestion along sections of the M6 feeding into the Birmingham metropolitan area, and is the only intercity toll road in the UK. Between 2006 and 2012, the total traffic on major roads nationally and across the West Midlands region decreased by 2% and 0.4% respectively (Campaign for Better Transport, 2013). Across the same timeframe, the average daily traffic levels on the 'M6 Toll' decreased by 24% (9,700 fewer vehicles per day), whereas the levels on the parallel section of the M6 increased by 1.5% (1,700 more vehicles per day) (Campaign for Better Transport, 2013). The daily traffic flows of 41,473 across all vehicles and 1,869 for HGV's in 2007 declined by 18.7% and 26.6% respectively in 2012 following a progressive rise in the M6 toll (£3 per car and £6 per HGV in 2007; £5.50 per car and £11 per HGV in 2012).

Walsall Council (2007) and Bandeira *et al* (2012) evaluated the impact of intercity toll pricing schemes on NO_2/NO_x reductions. However the screening assessment of Walsall Council (2007) does not to explore the environmental implications of the 'M6 Toll' on the surrounding road network. Bandeira *et al* (2012) demonstrated that a 10% traffic reduction in daily traffic flows of 48,000 vehicles on a Portuguese intercity corridor, by the introduction of a toll measure, would result in a 39.1 kg/day reduction in NOx emissions on the road in question.

Urban Road Tolls

The evidence is not clear in the literature of the impact of urban road tolls on a potential reduction in traffic and hence a reduction in NO_x emissions. Bureau & Glachant's (2008) predictions of the impact from a theoretical toll system around Paris showed some complexities depending on whether drivers were of high or low income status. The study suggests that high income motorists value their time more than low income motorists and continued to use the road with the introduction of a toll as congestion reduced and journey times reduced. Tolls should in theory reduce traffic but this study indicates that the level, if any, of traffic reduction depends on the income status of many of the users of the road and viable alternative public transport. This will inevitably have a direct impact on the potential change in NO_x emissions which could result from the introduction of a road toll.

Another study by Kallbekken *et al* (2013) found that only 21.7% of the 1,152 individuals surveyed within the largest urban centres of Norway believed that road pricing improves environmental quality. 26.2%, 20.9% and 33.3% of the respondents in Oslo, Bergen and Trondheim respectively believed/strongly believed that road pricing reduces congestion and therefore their implementation could be more acceptable than previously reported. Although Kallebekken *et al* (2013) did not report on the impact on NO_x emissions, there is an implication that if congestion is reduced, emissions of NO_x are also likely to reduce.

High-Occupancy Road Toll (HOT) lanes

High-Occupancy Toll (HOT) lanes are a road pricing scheme that gives motorists with more than one occupant free access to high-occupancy vehicle lanes, while single-occupant vehicles pay a toll determined by demand.

Finkleman *et al's* (2011) exploration into the public acceptability of HOT lanes in Toronto, found that there was a willingness to utilise higher efficiency modes across all income levels. 67.8% and 41.4% of drivers from low and high income groups respectively reported that they would consider carpooling, and for the same two groups 69.5% and 41% respectively said they would consider a shift towards the use of public transport. This therefore suggests that a robust scheme designed to encourage car sharing, and hence result in a reduction in vehicle trips, could lead to a positive impact in NO_2 concentrations.

3.3.2 Wider Impacts and Unintended Consequences

Cordon Charging Scheme

Alterations to the vehicle fleet composition have been noted within the London Congestion Charge Zone (CCZ), with motorcycle, taxi and bus use increasing by 3%, 13% and 20%, respectively (Beevers & Carslaw, 2005). The implementation of a CCZ seems to have promoted a shift in car use which remained stable outside of the CCZ and declined by 29% within the CCZ. Use of buses has also been observed to increase by 20% along the inner ring-road (Beevers & Carslaw, 2005). But the expected increase in emissions from buses have been mostly offset by the widespread introduction of abatement technology to the existing bus fleet as well as the introduction of newer technology bus engines. In the UK, the Department for Transport has shown car occupancy levels to remain at a relatively stable level of 1.60 persons per vehicle between 1996 and 2008 (DfT, 2009); and parliamentarian records have indicated that in 2005 a bus carried on average 9 passengers per vehicle (UK House of Commons, 2005). Fleet weighted road-transport emission factors for 2011 indicate that the hot exhaust NOx emissions of a bus (8.003 g/km) equate to the contributions of either 44 petrol or 13 diesel cars (NAEI, 2013), which would hold approximately 21-70 passengers. Therefore a direct shift from private to public transportation modes with the existing stock of public transport may not necessarily be the best solution to a city's air quality problems, without fleet renewal or retrofitting strategies. Prud'homme & Bocarejo (2005) estimated that the London Congestion Charge Zone (CCZ) provides a net benefit of €73 million per annum, when applying pre and post-charge environmental, speed and road usage data to demand-cost curves.

Li *et al* (2012) found that since the introduction of the LEZ, the number of car casualties within the London CCZ had reduced by 5.2%. That was thought to be most likely due to the decrease in traffic volume. However, it was also shown that there was an increase of 5.7% in motorcycle casualties and 13.3% in bicycle casualties related to the CCZ. These negative outcomes were attributed to a 15% increase in inbound two wheeled vehicles and a 31% increase in the average traffic speed within the CCZ after its introduction (Li *et al* 2012).

Road User Scheme

The literature provides varying evidence of the costs and benefits impact of a road user scheme. For example c found that a road user scheme in Austria would generate €273m annually to improve wider transport facilities and €329m to improve welfare services. . Also in Paris, the modelled outputs of a proposed 228 km of automated highway in 2020 predicted that several economic benefits would result. This included 73,000 hours saved per evening rush hour and annual revenues of €522,435 for reinvestment back into the local transport network (Marin, 2003). However, losses of around £26 million a year have been reported for the operational cost of the UK M6 Toll between the road's opening, with the roads maximum daily uptake nowhere near the predicted patronage levels of 75,000 vehicles per day (Campaign for Better Transport, 2013).

Concern was evident in the literature on the impact of road user scheme on social equality. In the UK, current weekly road charges in Britain of £25 entry into the London congestion charging zone and £30 for two-way use of the M6 toll road, it is apparent that existing schemes have a risk of unfairly pricing those the lowest income groups off the roads. In addition, populations surveyed had concern of the impact on social equality. For example, Kallbekken *et al* (2013) found that 69.9% of 1,152 individuals surveyed within the largest urban centres of Norway strongly believed that road pricing has a negative impact on the welfare of the poor. In the USA, c) explored the following RUC schemes across Maryland State

1. Replacing Maryland state fuel tax with a RUC based tax = $0.0102 per mile
2. RUC tax increase = $0.015 per mile
3. RUC public transport subsidy tax = 0.8 x fare ($/trip)

Replacing the Maryland state fuel tax with a vehicle miles travelled (VMT) that is equivalent to the per mile cost of fuel for the average fleet efficiency (RUC Scheme 1) was observed to provide a $27.1 per capita annual welfare benefit for the lowest income groups (with annual earnings of <$29,000) compared to a $34.17 per capita loss amongst higher income groups (with annual earnings of $100,000-149,999). Although the overall daily vehicle miles travelled and vehicle hours decrease by 1.0% and 1.3% respectively, the reduction in travel cost to the lower-income groups would encourage travel by personal vehicle over public transport (Welch & Mishra, 2014). This increased demand in short trips is likely to cause a slight increase in congestion, which would burden higher income groups further, due to their added sensitivity to travel time.

Whilst a $0.015 per mile charge would result in a 2.1% and 2.6% decrease in daily vehicle miles travelled and vehicle hours, negative per capita annual welfare benefits are expected to be experienced by both poor (-$8.5) and affluent ($-74.72) sectors of society (Welch & Mishra 2014). This emphasises the difficulties that exist in formulating a suitable pricing scheme. The only scenario to produce a welfare gain for all income groups ($25.29 to $46.98 gain per capita) is using RUC tax revenue to pay for a 20% transit fare subsidy provided across the board for all travellers; however, the effect of this subsidy results in the greatest welfare gain for the high-income group (Welch & Mishra 2014).

Road Tolls

In a simulation of nine toll scenarios for Paris using the travel information of 10,500 households surveyed, Bureau & Glachant's (2008) found that low-income motorists would lose out more than affluent motorists even when low impact tolls were introduced. For instance, a 10% traffic reduction due to a €0.70 toll per trip would respectively amount to a loss of €0.64 and €0.10 per trip for those poorest and most affluent motorists, after adjusting for any welfare gains. High income motorists who are also individuals with a high value of time tend to place more value on congestion reduction and are less affected by the toll's financial burden, and as such would tend to lose less than low-income motorists. An alternative toll using any net revenues used to subsidise public transport fares, could reduce traffic by 20% (Bureau & Glachant, 2008). One would expect public transport funding to be more favourable to low income individuals as motorists are more likely to be from high income groups than public transport users.

3.3.3 Implementation Success Criteria

A UK nationwide survey of 258 local authority members, academics and stakeholders identified the most effective policy options for reducing traffic congestion in towns and cities as

- Restriction of vehicles in central areas (87.4%),
- Implementation of urban road pricing (81.6%),
- Development of a land use and transport planning strategy (80.8%), and
- Improved frequency and reliability of public transport (77.4%) (Ison, 2000).

However, several concerns were raised specifically in relation to the implementation of urban road pricing, specifically relating to:

- The use of revenue (93.6%),
- Public transport provision (92.8%),
- Clear environmental and or monetary objectives (91.6%),
- Enforcement (82.8%), and
- The economic impacts on the immediate urban area (83.2%) (Ison, 2000).

Ison (2000) concluded that the success of a road user scheme was highly dependent on the design features and how the scheme was implemented.

A system of road-user charging for lorries (LRUC) was conceptualised in the UK after the fuel crisis of September 2000 when road hauliers (and farmers) blockaded oil refineries and blocked roads in protest against high fuel taxes (McKinnon, 2006). The LRUC programme would have operated a fuel-duty repayment system determined for the majority of users by an ‘on-board unit’ which relayed movements to a control centre, with occasional users (<12,000 km/year) paying a determined rate into the system. It has been estimated that the contract for setting up and running LRUC over a 10-year-period across the entire UK road network would have cost £4 billion, with foreign-registered vehicles paying £140-189 million per annum if tolled (McKinnon, 2006). A second phase of the scheme was planned to introduce geographical environmental zoning to encourage the uptake of newer low emission vehicles, though the cost of implementation was high relative to the small benefits (McKinnon, 2006). The scheme was abandoned in July 2005.

A German social experiment into the complexity of cordon charge schemes identified difficulties in comprehending such measures ($P<0.01$) amongst elderly participants (>60 years old), and to a lesser extent between the sexes with women demonstrating a better understanding (Francke & Kaniok, 2013). Prior to implementing such a scheme, it would therefore be wise to educate specific sectors of society. Across the general population, the rankings of the hypothetical pricing schemes revealed that a distance-based cordon charge was preferred, followed by monthly lump sum, temporally and spatially differentiated charges, temporally differentiated charges and finally a fixed charge per journey (Francke & Kaniok, 2013).

4 Low Emission Zone Package of Measures

Box 5: Key Findings: Low Emission Zone Package of Measures

- Low Emission Zones (LEZs) are reported in the literature as one of the more effective measures to improve air quality in the locations where most improvement is required for the protection of human health i.e. in many of our towns and cities.
- There are many hundred examples of LEZs across Europe and around the world. Some countries, such as Germany, have a well-established National Framework on LEZs, setting out the key design criteria. Here, the evidence indicates particular high levels of public acceptability of LEZs. However, Italy does not adhere to this pattern as public acceptability (as measured by the number of LEZs) is high but no national framework is in place but there is a central encouragement of LEZs. In other Member States such as France and Spain there appears little encouragement of LEZs at the national level and the number of LEZs is correspondingly lower.
- Although the UK has the largest LEZ in the world in London, there is only modest implementation of LEZs to improve air quality, despite clear compliance issues to achieve air quality to protect human health.
- Evidence on the effectiveness of LEZs across Europe is mixed. It is recognised that the majority of LEZs have been implemented to reduce PM_{10} emissions but a confounding factor is that only a relatively small proportion of PM is derived from vehicle sources. In continental Europe meteorological factors, particularly in winter when emissions are higher, have a direct influence on PM concentration levels. In addition, while LEZs have focussed on PM emissions, it is now evident that NOx emissions under real driving conditions have not performed according to Euro test conditions. Once real world driving emissions are aligned with test conditions, only then can the true effectiveness of LEZs focussed on NO_x emissions be realised. It should be noted that early indications of the Oxford bus LEZ to reduce NO_x emissions appears to have achieved compliance with the hourly NO_2 Limit Value. Further analysis is required.
- Evidence suggests that national LEZ frameworks or very active government encouragement highly increases the establishment of LEZs at city level. Recent evidence (Malina & Scheffler, 2015) indicate that if there is a large compliance gap between current concentrations levels and the limit value LEZs are an effective measure but the vehicle emission standard that delivers in the real world are recognised as an important design feature.
- The successful implementation of a LEZ requires a consistent set of design criteria, preferably in a national LEZ framework, supplemented with complementary measures and a communications plan.
- The implementation of a LEZ requires coordination with other measures that are likely to be applied in the same policy context to achieve greatest impact. Examples of these additional measures are promoting retrofitting to achieve compliance with emission standards, incentivising the uptake of cleaner vehicle technologies through funding schemes or shifting freight to other transport modes such as railways.

4.1 Low Emission Zones

There are two main categories of low emission zones, based on whether they are “actively” or “passively” enforced. Table 5 shows the cities where these active and passive low emission zones have been implemented.

Table 5: Low emission charging measures overview

Low Emission Enforcement	Low Emission Scheme	City
Active (e.g. ANPR)	Low Emission Zone (LEZ): Buses, Coaches & HGV's	Multiple Danish Cities Multiple Dutch Cities
	Low Emission Zone (LEZ): All Vehicles	Milan Munich Stockholm Basque Country, Spain Brisbane City
	Low Emission Zone (LEZ): Various Models	Copenhagen London Oxford Multiple cities
	Green Activity Zones (GAZ)	Norwegian Cities
Passive (e.g. permit)	Environmental Zones (EZ)	Göteborg Stockholm

Low Emission Zones (LEZ) actively seek to prevent those most polluting vehicles from entering typically a central urban area through the administration of either a ban or a tiered charging structure, generally through a network of Automatic Number Plate Recognition (ANPR) Cameras if natural barriers do not exist. LEZs have tended to focus on the reduction of PM_{10} emissions to achieve compliance by the earlier limit value achievement date of 2005 compared to NO_2 limit values with a compliance date of 2010. Many LEZs were established before and just after 2010. Typically, LEZs are implemented in a staged approach for example stage 1 of a LEZ requires vehicles to meet Euro III emissions standards in order to avoid either a daily road use or cordon charge, with stage 2 introducing more stringent standards (Euro IV+) at a later date as is the case in Amsterdam (Boogaard *et al,* 2012, Panteliadis *et al,* 2014) and Copenhagen (Jensen *et al* 2011a). For instance, Pre-Euro and Euro I trucks were forbidden from entering Amsterdam from July 2007, whereas Euro II trucks were only allowed if retrofitted with particulate filters (stage 1) and restrictions were extended to cover Euro III trucks in 2010 (stage 2). In September 2008, stage 1 requirements were applied to buses and trucks entering Copenhagen, with stage 2 occurring in July 2010.

Green Activity Zone's (GAZ) are a conceptualised Norwegian variation of active LEZs which exclusively targets heavy-duty vehicles, whereby the amount charged is a function of continuous measurement of emissions from a vehicle. The fees are calculated using a differentiated pricing of local pollutants (NOx, PM, hydrocarbons HC and CO), which are spatially and temporally weighted to reflect specific environmental sensitive areas in the city. The technology and algorithms for these types of calculations have been recently developed (Tretvik, 2014).

In contrast to the aforementioned examples of LEZ, 'Environmental Zones' aim to improve air quality and reduce noise through requiring, for example, all diesel heavy-duty vehicles greater than 3.5 tonnes to meet a specified Euro emission standard, with older vehicles requiring the retrofitting of a certified emissions control device or new engine to continue operating within the zone. In contrast to an active LEZ, such schemes are passive in nature (low implementation cost) with zone enforcement of older vehicles through a permit system (windscreen stickers), and fining with illegal vehicles by police authorities. Passive enforcement LEZs can also be linked to speed enforcement or traffic calming measures preserving vehicle flows, which may significantly alter the operational factors influencing vehicle emission rates at the expense of travel time. For instance, the highest emissions of CO, PM and HC (including benzene) tend to occur at low average speeds (< 20 km/h) as these pollutants are products of incomplete combustion, whereas nitrogen oxide emissions substantially increase with speeds ≥100 km/h under high engine pressures and temperatures (Owen, 2005).

One of the latest proposals for a LEZ in Europe is the Ultra-Low Emission Zone in London which would require all vehicles driving in central London to meet new exhaust emissions standards (Euro VI/6 or Euro 4 if petrol car) and would take effect from 7 September 2020. A vehicle that does not meet the ULEZ standards could still be driven in central London but a daily charge would have to have been paid to do so. By 2020, the oldest Euro VI HGV will be six years old, whilst the oldest Euro diesel 6 car will be five years old. The oldest Euro 4 petrol car would be fourteen years old. The modelling presented in the impact assessment indicates that the ULEZ has the potential to result in a reduction in further NOx emissions by 51% in 2020 compared to the reduction without the ULEZ (Transport for London, 2015)

4.1.1 Impacts of the Measure on NO_2 and Potential Effectiveness

Heavy-Duty Vehicles Only

Denmark's LEZ Act in 2008 required trucks and buses below a Euro-III emission standard to be equipped with particle filters in order to enter a low emission zone. It was further tightened in 2010 to include Euro-III vehicles. NO_x emissions from heavy-duty vehicles were reduced by 25% **(**a 17% reduction for smaller trucks (<32t), 8% for larger trucks and 40% for buses) (Jensen *et al,* 2011a). However, the sizeable reduction in NO_x emissions from buses could not be attributed to the implementation of LEZ alone as it was also driven by environmental requirements of public procurement on urban buses. The effects of the LEZ for street level NO_2 concentrations in 2010 show reductions of 4%, 4%, 7% and 11% in H.C. Andersens Boulevard (Copenhagen), Albanigade (Odense), Vesterbro (Aalborg) and Banegårdsvej (Aarhus) respectively (Jensen *et al*, 2011a). However, the effects of natural fleet renewal show that by 2015 an additional 1-2μg m^{-3} reduction in NO_2 concentrations with the LEZ compared to without the LEZ, and close to zero in 2020 (Jensen *et al,* 2011b). As such, the effect of a LEZ corresponds to an accelerated introduction of newer Euro emission standards than otherwise would be the case and the effect of which will diminish over time.

Boogaard *et al,* (2012) investigated air pollution at street level before and after implementation of LEZs targeted at heavy-duty vehicles (trucks only) across the Netherlands. The investigation reveals that on average, daily traffic flows in the LEZs reduced by 9.8% two years after implementation, resulting in a 6.2% reduction in NO_2 concentrations (Table 6). However, in some cities there were very small changes in traffic flows with small changes in NO_2 concentrations. Pre-LEZ, 22% of truck traffic was below Euro III emission standards and not retrofitted with particle traps, whereas post-LEZ this reduced to 7%. This would suggest that LEZs increase the rate of fleet renewal of the most polluting vehicles. However, the NO_2 concentrations decreased most in those cities which also saw a reduction in traffic volume alongside fleet renewal.

Table 6 Impact of low emission zones on daily traffic flows and NO_2 ambient air pollution concentrations (Adapted from Boogaard *et al,* 2012)

Urban Municipality	Street	Traffic flows 24-h		Annual average NO_2 concentration ($\mu g\ m^{-3}$)	
		Pre LEZ (2008)	LEZ (2010)	Pre LEZ (2008)	LEZ (2010)
Amsterdam	Haarlemmerweg	15,253	15,314 (+0.4%)	54.3	50.9 (-6.3%)
	Hoofdweg	9,774	8,375 (-14.3%)	47.5	41.4 (-12.8%)
The Hague[5]	Stille Veerkade	17,438	8,471 (-51.4%)	54.1	40.7 (-24.8%)
Den Bosch	Brugstraat	17,896	18,170 (+1.5%)	53.9	53.3 (-1.1%)
	Koningsweg	17,138	16,876 (-1.5%)	44.2	39.3 (-11.1%)
Tilburg	Hart Van Brabantlaan	18,812	19,010 (+1.1%)	36.6	37.9 (+3.6%)
Utrecht	Vleutenseweg	13,553	11,158 (-17.7%)	41.7	44.1 (+5.8%)
	Weerdsingel Wz.	14,831	15,045 (+1.4%)	52.4	52.7 (+0.6%)
AVERAGE		**15,587**	**14,057 (-9.8%)**	**48.1**	**45.1 (-6.2%)**

Multiple Scenarios

A LEZ was established in the centre of Oxford requiring all buses within the LEZ to comply with Euro V emission standard for NO_x by 1 January 2014 (Oxford City Council, 2006). The council has reported a decrease in hourly exceedance of the NO_2 limit value from 58 exceedances in 2010, 12 in 2013 and no exceedances in 2014 (Air quality news, 2016). However, recent studies (Carslaw & Priestman, 2015) recorded large variations in emissions of Euro V buses with Selective Catalytic Reduction (SCR) to remove NO_x emissions in Oxford. This was up to a factor of 6 and some Euro V SCR buses had higher emissions than older Euro classes. In addition, primary NO_2 emissions were found to have even larger variation with the highest NO_x emitting bus also showed the lowest primary NO_2 emissions.

Sinclair *et al*'s (2013) Sheffield air quality modelling LEZ feasibility study has shown that while 80% of the city's fleet comprised private cars, these vehicles contributed just over 50% of NO_x emissions, of which 35% were emitted by diesel cars. Furthermore, the difference between petrol and diesel car NO_x emissions is growing over time, as the latest modern Euro emissions standards are successfully reducing the NO_x emissions from petrol engines, in contrast to diesel engines. The effects of natural fleet renewal have been predicted to produce a 4.9% reduction in Sheffield's overall NO_x emissions by 2015, with a 34.8% reduction on today's levels expected by 2020. The taxi fleet show little reduction in overall NO_x by natural fleet renewal and is a target for policy measures in the city (Table 7). Tate (2013) also reported that due to the high mileage and stop/start style of the driving, private hire taxis emitted approximately 30% more than their private car equivalents.

[5] It is unclear if these results adequately reflect year on year fluctuations in the annual average

Table 7. The effects of natural fleet renewal on overall NOx emissions in Sheffield (Adapted from Sinclair *et al* 2013)

Fleet Component	Contribution to Total Change in NO_x emissions (%)	
	Natural fleet renewal by 2015	Natural fleet renewal by 2020
Private Car – Petrol	-3.3	-8.1
Private Car – Diesel	-1.6	-11.9
Private Car – Other	0	0
Taxi – Hackney	+0.2	-1.5
Taxi – Other	+0.2	-0.5
LGV	+0.1	-4.8
HGV	+0.5	-5.5
Bus - Single Decker	+0.2	-0.5
Bus - Double Decker	+1.2	-2
TOTAL	-4.9	-34.8

Several LEZ scenarios were developed for Sheffield and are presented in Table 8 which shows the impact of various LEZ scenarios on the fleet composition, reduction in NO_x emissions and cost. The Sheffield study indicates that the most cost effective measures focus on the removal of diesel vehicles to petrol or CNG or equivalent.

Table 8 Overview of the main strategies presented in the Sheffield air quality modelling LEZ feasibility study (Adapted from Sinclair *et al,* 2013)

LEZ Scheme	LEZ Strategy	Fleet Affected (%)	Total reduction in NO_x emissions (%)	Cost per total fleet of 1000 vehicles (million £)
Emission Standard	Taxi & Bus Euro V+	5	8	1
	Taxi & Bus Euro VI+	6	19	10
	Taxi, Bus & Goods vehicles Euro V+	12	5	< 1
	Taxi, Bus & Goods vehicles Euro VI+	18	40	1-5
Fuel	100% Diesel vehicles switch to petrol: Car, LGV, Taxi	46	48	< 1
	100% Diesel vehicles switch to petrol or CHG/equivalent: Car, LGV, Taxi, Hackney, HGV, Bus	51	66	1-5
	100% Private Diesel Cars switch to petrol	32	33	< 1
	100% Private Diesel Cars removed and not replaced	32	41	1-5
'Worst polluting' vehicles	10-25% worst Taxi, Bus & Goods vehicles	4	14	5-10
	35-45% worst Taxi, Bus & Goods vehicles	8	22	5-10
	50-65% worst Taxi, Bus & Goods vehicles	11	27	5-10

The London LEZ scheme was introduced in 2008 and targeted at HGVs and buses, with an emission standard of Euro III. In 2012 the scheme was widened to include vans and minibuses, and the standard for HGVs and buses was tightened to Euro IV. The LEZ in Berlin was introduced in the same year and was targeted at all diesel vehicles and currently has a standard Euro IV/4 or Euro III plus particulate filter. The scheme in Stockholm restricts access to all HGVs and buses older than 6 years, with exceptions for approved retrofit technology.

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

A recent study of the impact of the London LEZ showed that the scheme had a significant initial impact on the fleet composition operating in the city, with a shift to ensure compliance (Ellison, 2013). In terms of impact on air quality the study found a small impact on PM concentrations of some 1% improvement per year in relation to areas outside the LEZ. However**,** no discernible improvement was seen in NO_2 concentrations.

An analysis of the impact of stage 1 of the Berlin LEZ also showed a major improvement in the vehicle fleet and estimated that this had led to a decrease in vehicle emissions of PM and NOx of 24 and 14%, respectively. However, in terms of air pollution concentrations results of a source apportionment study for a measurement site in the city centre, indicated a 3% decrease in the PM_{10} concentration and little in terms of NO_x (Lutz, 2009).

A study of 5 schemes in the Netherlands, directed at heavy vehicles, found limited impacts on overall pollution concentrations of schemes of that scale (Boogaard, 2012). Another review of LEZ schemes also suggested that they did not necessarily perform as had been expected (Barratt, 2013) in terms of reducing pollutant concentrations. The greatest impact of many LEZs appears to have been a reduction in fine particulate matter ($PM_{2.5}$) and black carbon, related largely to the introduction of particulate filters as a result of the scheme. Similarly areas of high HGV traffic have shown greater impacts compared to other areas as HGV's are generally a key target of the schemes. The impact on overall PM_{10} and NO_2 levels has been considerably less.

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

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

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

- Set up costs - covering feasibility/consultancy, legal costs, and consultation
- Capital costs - including enforcement systems, signage and public realm works, back office administration systems.
- Operating costs – for the enforcement and back office systems
- Revenues – from fines
- Compliance costs – for the users in terms of purchasing new vehicles or modifying existing vehicles.

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

Environmental Zone

Environmental Zones (EZ) were introduced in several major Scandinavian urban areas in the 1990's, with the aim of removing heavy-duty diesel engine vehicles from roads which did not meet the Euro-I emission standard through the use of windscreen permitting. Whilst these zones remain enforced they are yet to be updated to the more stringent emission standards found in other LEZs and therefore the impact is not likely to be comparable to the current emission situation.

Still, these passive low emission charges with self-regulation would appear to have remained a largely successful measure with the proportion of vehicles not entitled to enter the Stockholm, Göteborg and Malmö's EZ's in 1997 and 2004, respectively recorded at 5% and 3% (Göteborg's Stad Trafikkontoret 2006). In Göteborg, the EZ covers around 15 km^2 housing approximately 100,000 inhabitants. Scenario models for Göteborg in 2005 hold the EZ accountable for a 7.8% reduction in NO_x emissions, which is a relatively large gain when accounting for the schemes low implementation and running costs (Göteborg's Stad Trafikkontoret, 2006).

New Evidence

As stated in the methodology section 2, there was an extended period between the evidence review activity and finalisation of this project, which enabled a further limited review of the most recent literature during 2015 and early 2016. There have been three key papers providing evidence on the effectiveness of LEZs published during 2015/16. Holman *et al* (2015) reviewed the effectiveness of LEZs across five Member States in Europe. Evidence presented indicated a neutral impact with the German LEZs that target cars alongside HDVs as monitoring data show only a few percent improvement in long term PM_{10} and NO_2. Where LEZs have been restricted to HDVs there appears no clear evidence of an impact on pollutant levels. However, Holman *et al* (2015) go on to suggest that there may be a number of confounding factors, including meteorology and as traffic is not a large contributor to PM_{10} so $PM_{2.5}$ may be a more appropriate metric as a key performance indicator.

Ferreria *et al* (2015) reported on the effectiveness of the LEZ in Lisbon, Portugal. Both PM_{10} and NO_2 limit values have been exceeded in the city since 2001 mainly due to road transport sources. Lisbon's LEZ has been implemented in different stages, progressively expanding its area, including more vehicle types (for example, by repealing the exemption for public transport buses), and adopting more stringent requirements in terms of minimum emission standards required to access the LEZ. The first phase began in July 2011. The analysis of the air quality data before and after the LEZ phase 2 has shown a positive impact when comparing the period between 2011 (before measures) and 2013 (after measures). In 2013, there was a reduction in PM_{10} annual average concentration of 23% and NO_2 annual average concentrations of 12%, compared with the year 2011. Although PM_{10} reductions were more significant inside the LEZ area, the same was not valid for NO_2, suggesting that the implementation of these measures was not as effective in reducing NO_2 levels. The results from road traffic characterization indicate a relevant effect on fleet renewal with an overall decrease in the relative weight of pre-Euro 2 vehicles in 2012/2013, compared with data from 2011. An important increase in the share of Euro 4 and Euro 5 vehicles was also observed. An important conclusion from Ferreria *et al* (2015) is that, stricter restriction standards should be enforced in the future stages of the Lisbon LEZ in conjunction with a higher effort and investment on LEZ enforcement to result in further improvement in air quality.

A further study on the effectiveness of German LEZs was presented by Malina & Scheffler (2015). LEZs began to be introduced in Germany in 2007 to comply with PM_{10} limit values. The type (level of restriction) of LEZ were compared with meteorological factors with cities without LEZs. As there are many cities with LEZs in Germany the sample size was high. The key finding of the paper is a decrease in urban PM_{10} levels that can be attributed to the introduction of LEZs. Malina & Scheffler (2015) also found that more stringent zones (stage 2 zones) reduce PM_{10} concentrations more than three times as much as stage 1 zones.

The conclusions from the evidence are that LEZs do result in increased rates of fleet renewal. Most improvement in PM_{10} concentrations has been achieved where later Euro standards are used. Little success in reducing NO_2 concentrations is evident in LEZs across Europe. However, all of these rely on pre-Euro 6 emission standards, where these have been well documented in the literature to not deliver in the real world and therefore is likely to explain some, if not most, of the failure of LEZs to improve NO_2 concentrations.

4.1.2 Wider Impacts and Unintended Consequences

Environmental

Like the London Congestion Charging Scheme, the London LEZ also appears to have had an effect on the composition of the wider vehicle fleet, with the proportion of pre-Euro III rigid vehicles in London declining from 56.3% in 2006 to 19.4% in 2011; compared with a national shift from 51.4% to 29.8% over the same period (Ellison *et al*, 2013). It must also be noted that there is a challenge and tension between reducing emissions of CO_2, PM and NOx. Retrofitting particle traps in 2005 resulted in increased primary NO_2 emissions from buses (Barratt, 2013). To develop an outcome to satisfy the aims of all emission reduction may not be straightforward.

Percoco, (2014a) estimated that before and (11-months) after the Ecopass came into force in Milan, 98,000 and 87,700 vehicles per day respectively entered the restricted area. 19,100 additional daily passengers used surface public transportation services resulting in a 25.1% reduction in congested kilometres across the interior traffic network and a 4.0% travel speed improvement, ultimately translating into a €9.3 million annual saving. On 25th July 2012 an unexpected 50 day suspension of the Ecopass zone was imposed because of a ruling by the Council of State following protests by parking owners in the centre of the city. During the suspension period, while the total number of vehicles circulating the city centre remaining unchanged, there was a significant shift in modes of transport or vehicle type (the use of bi-fuel and hybrid cars reduced by 17%, the use of motorbikes reduced by 21%, and the use of Pre-Euro to Euro III cars increased by 13% and Pre-Euro to Euro III cars increased by 20%) (Percoco, 2014a). The level of shift in modes of transport from private vehicle to public transport or motorbike etc will have a bearing on the potential effectiveness of the LEZ to improve NO_2 levels, alongside the Euro Emission standard adopted.

Economic

In 2007, 170,000 older cars and motorcycles that did not pass emission standards (Euro III) were banned from entering the inner-city of Milan. In January 2008, the “Ecopass programme” was launched to restrict traffic entering an 8km^2 central zone (Percoco, 2014a). Milan’s Ecopass comprises three segments:

1. Outer: No traffic restrictions;
2. Intermediate: Subject to the congestion traffic charge called “Ecopass”, where a ticket is required to enter for cars equipped with engines prior to Euro IV standard
3. Inner: Pedestrian zone (no cars admitted) of Duomo Square in the city centre

The charge depended on the vehicle's engine emissions standard with fees varying from €2 to €10 on weekdays from 07:30 to 19:30, with free access granted to motorbikes, alternative fuel vehicles and to conventional fuel vehicles compliant with Euro IV or better. More polluting vehicles received a discount only if they bought an annual pass that could cost up to €250 (Percoco, 2014a). Public administration revenues (sum of charge payments and penalty payments) are estimated to be €12.4 million, almost 25 times less than that in London. That was partly due to the smaller geographical area and lower average charges (Rotaris *et al,* 2010). The average value of travel time savings (VTTS) of the current Milan Ecopass system (passengers = €15.59, freight = €15.59, surface public transport = €10.98) equate to a €6,000,000 net gain.

An analysis of the impact of the Ecopass zones in Milan on house prices between 2006 and 2009 (2 years before and 2 years after introduction) has found house prices dropped by 1.2-1.8% in areas where road pricing measures exist, which equates to a reduction of approximately €67-101 per square metre (Percoco, 2014b). Residents in the city centre were not exempted and had to pay an annual charge of €50-250 euros depending on the type of engine in their vehicle. Inner city residents thus face a double financial burden.

4.1.3 Implementation Success Criteria

Evidence shows that there is a wide variety of LEZ designs, with a variety of vehicle types included. Most are focussed on the reduction of PM_{10} emissions but some also aim to reduce NO_x emissions. While there is no comprehensive review of what makes for a successful LEZ, clearly the design criteria are key to acceptable and successful implementation. Across Europe there are some 455 Environmental Zones including LEZs, Congestion charging zones and Access Restriction Zones. Over 200 of these are LEZs focussed on the reduction of PM_{10} emissions in the most cases. Most LEZs are in Germany (84) and Italy (101), then The Netherlands (11). In the UK there are five LEZs in Greater London, Oxford, Norwich, Brighton and Nottingham, with the ones outside of London being restricted to buses. In the UK there are plans to implement an Ultra LEZ in central London which will target cars along with the existing HGVs, vans and buses.

Some implementation criteria are considered below, adapted from Sadler Consultants (2015) on urban access regulations website:

Vehicle type: *Only the Italian LEZs apply to all vehicles, but these have different standards and time periods. All 4 wheel vehicles apply in LEZs in Germany, Lisbon, Athens and the Netherlands. Only Heavy Duty Vehicles apply in London (this has since been extended to include vans), Finland, Denmark and Sweden. Heavy Goods Vehicles (lorries) apply in Austria and Prague. In the UK cities have Bus-only LEZs including Norwich, Oxford, Brighton and Nottingham.*

Hours of operation*: Most LEZs operate permanently with notable exceptions in Italy where LEZs sometimes operate at peak or other selected times. In Lisbon, Prague and Budapest LEZs operate weekday daytime, Athens is weekday daytime and evening. In addition some Italian LEZs and Athens LEZs are not in operation all year round (are operational in winter). However, notably in Italy LEZs are becoming increasingly permanent and operate 24/7.*

Enforcement mechanism: *The majority of LEZs across Europe are manually enforced but cameras and transponders (electronic device that transmits payments to the toll-stations) are also used, generally country-by-country, as below:*

- *Manual enforcement is used in the Swedish, Austrian motorway and German LEZs.*
- *The Dutch LEZs started with manual enforcement but have now moved to camera enforcement*
- *Most Italian LEZs are manually enforced however a few have camera or even electronic enforcement, often when combined with another scheme or pedestrian zone.*
- *The Danish LEZs set out the 3 manual enforcement methods: Firstly municipal inspectors when lorries are visiting a company; Secondly town traffic wardens checking vehicles parked on the street; Finally, police at routine roadside checks. Both inspectors and traffic wardens can call on the police when needed.*
- *The London LEZ and Milan Ecopass are camera enforced*
- *The Norwich and Oxford LEZs (UK) are enforced through agreements with the local bus operators.*
- *The planned Norwegian LEZs intend to use the same electronic device system as used for motorway tolls, with camera and manual enforcement also possible, as well as cameras to enforce those who do not pay.*

National LEZ Framework: *There are a number of national LEZ frameworks in place including in Germany, Denmark, the Netherlands, Sweden and Czech Republic. Austria and Norway are preparing a National LEZ framework. The advantage is an accepted system which cities can join. The national scheme sets out the same emission standards and enforcement methods to be adopted. From the driver's view there is consistency across cities limiting confusion. Germany has had a national LEZ framework in place for many years which a nationally recognised sticker enforcement system. To enter a zone a sticker must be bought and displayed on the windscreen showing the emission standard of the vehicle. The police are responsible for enforcement. Denmark and Sweden have a similar LEZ framework to Germany. It could be concluded from the evidence that a National LEZ framework encourages cities to implement a LEZ – there are over 60 LEZ in Germany for example. However, in Italy with no national framework there are over 20 LEZs. Other countries with no national framework have low uptake of LEZs, for example in France there is one LEZ in the Mont Blanc Tunnel and Paris has an odd even vehicle registration place restriction during episodic pollution events.*

Spain similarly has a poor track record of LEZ uptake with only three access restriction zones. On balance, the evidence indicates that the adoption of a national LEZ framework does lead to more cities implementing LEZs.

Communications Plan: *Evidence from Germany shows that communication with the population is an essential element of effective LEZs. The purpose of a LEZ should be explained as early as possible, along with its benefits for citizens. This includes information about the possibilities to fit vehicles with emission abatement or to change to a lower emission vehicle. Alongside this technical information, alternatives such as cycling and walking should be promoted including public transport. For the public acceptance of a LEZ it is important to make the measurement information publically accessible, to explain it and to point out the relevant advances in health protection. A range of communication mechanisms should be used including press conferences, TV, social media etc. This was found to create understanding and acceptance among the population.*

Complementary measures: *LEZs may face strong political and societal opposition, typically on the grounds that they are overly burdensome and economically disadvantageous to operators of older vehicles. This opposition may be overcome by the introduction of retrofit or replacement subsidies for non-compliant vehicles in parallel with the implementation of the LEZ. In addition, improvements to bus and rail services are important along with focussed traffic improvement measures to discourage parking of vehicles just outside the LEZ boundary, to improve sustainable transport measures.*

4.2 Vehicle Scrappage

Box 6: Key findings: Vehicle Scrappage

- Scrappage schemes are a policy lever that reduce overall vehicle emissions by targeting those with the highest emissions.
- When the selection of vehicles to be retired is made carefully, the achieved emission reductions are comparable to the main alternative measures for reducing fleet emissions at a controlled cost.
- Scrappage actions have most impact when combined with appropriate taxation/incentives mechanisms that encourage the uptake of alternative fuel or smaller-capacity vehicles (downsizing).
- Scrappage schemes are perceived as expensive and are cost-effective only in the short term.

The literature indicates that the most targeted way of controlling older, high-emitting vehicles is to eliminate them from the fleet altogether through mandatory or heavily subsidised voluntary scrappage. HDV scrappage schemes typically address conventional pollutant emissions e.g. PM_{10} only, while in many countries light duty scrappage schemes have targeted both air pollutants and CO_2. In many cases scrappage schemes are successful in reducing emissions and stimulating economic growth. This is achieved as scrappage subsidies are offered on the condition that the vehicle owner simultaneously purchases a new (or nearly new) vehicle. The additional demand created in an aggressive scrappage scheme can help ensure demand for new vehicles as part of the transition to a newer, more stringent national emission standard.

Various scrappage schemes offer financial incentives for the replacement and retirement of old vehicles. They have been implemented for economic and/or environmental reasons (to reduce air pollution and greenhouse gas emissions). For example, in 2009, 13 Member States of the EU and the United States began scrappage schemes following the economic slowdown. These schemes were designed to stimulate the economy by boosting the car industry and aimed to remove some of the dirtier vehicles from the roads. In California, the Enhanced Fleet Modernization Program implemented in 2010 was aimed at retiring high polluting passenger vehicles and light and medium duty vehicles. The programme’s focus was on areas with the greatest potential for air quality impact.

Qualifying criteria for the schemes varied from country to country, in the UK the qualified vehicle had to be more than 10 years old with £1000 available from the government and £1000 from participating manufacturers (Cooke, 2010) with no set emissions requirement applied. In the German scheme, the qualified car had to be over 9 years old, and €2,500 was given for a Euro IV car up to 12 months. In France €1000 was given for a new car with 160g/km maximum CO_2 emissions. In 2011 Ford began a commercial scrappage programme for its London based customers as a result of the Low Emission Zone (LEZ). This covered between £1000 and £3000 off a new van when scrapping one over 10 years old.

4.2.1 Impacts of the Measure on NO_2 and Potential Effectiveness

In Europe vehicle scrappage schemes[6] had a general effect of steering buyers to lower emission cars (Leheyda & Verboven, 2013). It is expected that the scrappage schemes would result in a reduction in NO_x and PM emissions (IHS Global Insight, 2010). The UK Scrappage Incentive Scheme which lasted for nearly a year during 2009/2010 had generated nearly 400,000 new car registrations (about 20% of all new cars registered in the UK) over the period (SMMT, 2010).

4.2.2 Wider Impacts and Unintended Consequences

Vehicle scrappage schemes incentivise the purchase of cars as opposed to the use of public transport/environmentally friendly transport options (Aldred & Tepe, 2011). They may also lead to people driving more as found in the US and Japan because of the 'energy rebound effect' associated with coming into possession of fuel-efficient vehicles (Zolnik, 2012; Kagawa *et al.,* 2013). It is thought that vehicle use will increase by 5-15% in the US because of this rebound effect, thereby reducing the emissions benefits (Zolnik, 2012).

Increases in vehicle scrappage rate is expected to decrease fuel consumption, and hence emissions, in the US because of a faster fleet turnover (Cooke, 2010)

The vehicle scrappage schemes implemented in the UK and Germany during 2009 had mixed effects on car sales. Although the schemes temporarily boosted car sales, they also resulted in a delayed slowdown of car sales once the scheme finished (Leheyda & Verboven, 2013).

Vehicle scrappage schemes can have the unintended consequence of increasing emissions and resource consumption arising from the additional processes of scrapping old vehicles and producing the replacement new vehicles. They have impacts on the emissions of CO_2 as well as pollutants such as PM and NO_x.

A range of reductions in GHG emissions have been reported (e.g. large reductions by IHS Global Insight, 2010; Bendor & Ford, 2006; minor reductions by Aldred & Tepe, 2011). Some articles have reported that carbon and GHG emissions may actually increase on a life cycle basis (e.g. Brand *et al.,* 2013).

Kim *et al* (2004) studied the effectiveness of vehicle scrappage schemes by explicitly taking into account the environmental burdens from the production of additional new vehicles. The study sought to optimize a programme for the scrappage of older cars, based on the life cycle inventories of mid-sized internal combustion engine vehicles in the US. The projected effectiveness of a particular vehicle scrappage scheme depends on key factors such as the emission distributions with vehicle fleet age, the future emission scenarios associated with new vehicles, and the effectiveness of emission abatement with increasing vehicle mileage. The simulation results of their assumed factors showed that the scrapping of vehicles younger than 20 years old produces a net increase of CO_2 emissions but net reduction in the emissions of CO, Non-methane hydrocarbons (NMHC), and NO_x.

The Enhanced Fleet Modernization Program in California began in 2010 with a retirement only option offering $1000 to people for permanently retiring their vehicle, with the amount increasing to $1500 for people on a low income. As of 2013, the scheme ran out of money eight months into each year. In 2012, vouchers for the retirement and replacement scheme were implemented. This involved approaching around 11,000 motorists with the highest emitting vehicles and offering $3000 to retire their vehicle and replace it with a vehicle less than 4 years old. Like the retirement only scheme for low income groups, the voucher value increased to $4000 and the rules of the replacement were relaxed to a vehicle of less than 8 years old. With only 21 people (as of November 2013, California Air Resources Board) taking the vouchers, the scheme has not been as popular as the retirement only scheme.

[6] Schemes in Belgium, France, Germany, Greece, Italy, the Netherlands, Portugal, Spain and the United Kingdom.

It is perceived that scrappage schemes are an expensive way of achieving relatively small emission cuts (Aldred & Tepe, 2011; Kagawa *et al.,* 2013). In order to increase the cost effectiveness, it is recommended that the prices paid for vehicles are relatively low and the programmes are carried out in areas where abating pollution has a high value (e.g. urban areas) (Lenski *et al*., 2013). Vehicle scrappage may be cost-effective only in the short term (Zolnik, 2012). IHS Global Insight (2010) found that the vehicle scrapping schemes implemented in Europe during 2009 have cost the European Governments 7.9 billion euros in outlay, plus the cost of administration. It stated that 'Our aggregate calculation for 2009 is that vehicle scrapping schemes added a net 0.16–0.2% to EU-wide GDP'.

Public acceptability of vehicle scrappage schemes depends on how the schemes are advertised and perceived. For example, in Germany, products were presented as 'green' and at more affluent customers because there were risks to brand reputation around advertising the economic messages of vehicle scrappage (Aldred & Tepe, 2011). In contrast, in the UK, economic advertising was less threatening as one of the triggers for the take-up of vehicle scrappage in the UK was to save jobs.

The fact that scrappage schemes are usually voluntary may provide a practical barrier – the more money that is offered, the less likely this is to be a problem (Bendor & Ford, 2006). The appeal of scrappage schemes also weakens over time due to the fact that the gains of scrapping old vehicles decreases as the fleet's emissions levels reduce (Santos *et al*., 2010).

QCEA (2010) noted that scrappage schemes do not provide added security for workers in the automobile sector in the EU in the medium and long term. Furthermore, because most supply chains are international, scrappage schemes diminish the positive impact that could be had on domestic car industries and employment in the sector. 'Over 60 per cent of cars purchased under the German and U.S. scrapping schemes through July 2009 were foreign brands' (Schweinfurth, 2009).

4.2.3 Implementation Success Criteria

One consideration typically encountered in the implementation of a scrappage scheme relates to the fact that owner/operators of older vehicles are typically economically disadvantaged. Therefore, pricing mechanisms carefully tailored to ensure a good balance between environmental goals and economic fairness are important to successful schemes.

There is precedent for both mandatory and voluntary scrappage schemes. Mandatory schemes force retirement of the vehicle regardless of whether they have useful life remaining. These schemes are based on the age or mileage. Posada *et al* (2015) considered 10 case studies of scrappage schemes and found in China, for example, all classes of vehicle have an age and mileage limit. In Egypt, bus, taxi and other passenger service vehicles are prohibited if more than 20 years old. However, mandatory scrappage schemes are not common and are difficult to enforce.

More often scrappage schemes are voluntary and are incentivised by a pricing mechanism such as direct subsidies or fees to discourage older vehicle use such as a LEZ. Voluntary schemes are sometimes linked to retrofit programmes for HDVs to enable owners to reduce emissions in the most economical way for the given vehicle.

The scrappage subsidy is important to set at the right level to encourage uptake of the incentive acccording to Posada *et al* (2015). This was demonstrated in China in 2008 where the Ministry of Environmental Protection aimed to retire 10 million "yellow label" vehicles (< Euro 3 diesel or < Euro 1 petrol). The initial subsidy had to be increased twice to encourage uptake of the incentive to scrap.

One important implementation success criteria is the verification of the vehicle retirement. In the Beijing scrappage scheme there was no such verification and therefore it is not known how many vehicles were transferred out of the city to other areas where they continue to pollute.

From an evidence review, some best practices for the design and implementation of successful scrappage schemes are as follows (adapted from Posada *et al*, 2015):

1. *Ensure that replacement vehicles meet advanced emission standards and do achieve lower real world emissions*

   A scrappage scheme will only reduce emission if indeed they are cleaner than what they replace. To ensure this, replacement vehicles should ideally be certified to the highest emission standards (Euro VI/6). For example Transport for London require that bus replacement vehicles demonstrate appropriate NO_x controls.

2. *Ensure that replacement vehicles are similar in power and operation to the scrapped vehicles*

   The benefits of a scrappage/replacement scheme could be much smaller than anticipated if new vehicles are driven considerably more than scrapped vehicles or if the new vehicles have substantially more power than the replaced vehicles. A robust scheme establishes clear requirements both for scrappage eligibility and for performance and operation of replacement vehicles. For example the California Air Resources Board's scrappage scheme requires that the applicant demonstrates the condition of the vehicle to be scrapped. The replacement vehicles must operate in the same manner as the scrapped vehicle, for example the new vehicle's mileage cannot exceed that of the scrapped vehicle.

3. *Verify that the high emitting vehicles are indeed scrapped (rather than being transferred to an outer region)*

   The Californian and the US "Cash for Clunkers" scheme required stringent protocols to ensure full and final scrappage. However in 2009 a German scheme for light duty vehicles required only that the owners delivered them to a scrap yard with no proof of deactivation of the vehicle required. Consequently up to 50,000 vehicles received subsidies but were subsequently sold to other markets in Eastern Europe or Africa (Dougherty, 2009).

4. *Improve the cost-effectiveness of schemes by providing incentives based on competitive bidding*

   In most scrappage schemes, the demand for subsidies is higher than the available grants. To prioritise which vehicles are subsidised, policymakers may consider awarding a subsidy based on a cost effective metric per tonne of emission reduced. In California's scrappage scheme, standard emission factors are used, along with verified vehicle km and the grants are awarded based on cost effectives calculated on the basis of the cost of the new vehicle purchase and a weighted estimated surplus reduction in NO_x *and* PM_{10}.

5. *Allocate funding to local level policymakers to undertake individual determinations and implement projects*

   The size of the scrappage scheme dictates at what level it is best managed. A large national scale scheme has to be funded and administered by central government. However, ideally scheme implementation can be via local authorities with a more detailed understanding of local needs.

4.3 Vehicle Retrofit

Box 7: Key Findings: Vehicle Retrofit

- Exhaust Gas Recirculation (EGR) and Selective Catalytic Reduction (SCR) are the technologies most commonly retrofitted to reduce NO_x emissions from vehicles. The picture is complicated as there is large variation depending on fuel use, after treatment, Euro Standard, retrofit or not, and the proportion of primary NO_2 emissions also substantially varies.
- The importance of urban performance was clear in the literature, indeed where most NO_2 exceedances are. In urban areas driving speeds are lowest and it has been shown that SCR may not get hot enough to operate at the optimum level.
- Diesel Particulate Filters have been effective in reducing particulate emissions, though it is a problematic technology for vehicles with high urban driving e,g, taxis.
- PM reduction retrofits may be a cost effective means of reducing emissions from HDVs with expensive customized chassis or vehicles with long useful lifetimes.
- Retrofits may not always be appropriate to all HDVs due to cost, space and mounting constraints. For smaller vehicles with shorter useful lifetimes vehicle scrappage may be preferable.
- Robust verification systems which match emission control devices to engine type are crucial to ensuring retrofits reduce emissions for the remainder of the vehicle lifetime.

Vehicle retrofit consists of the implementation of an on-board device that allows vehicles with a determinate emission standard (i.e. Euro) to comply with more stringent standards by reducing the emission of pollutants through technical measures. Retrofit measures are usually either Exhaust Gas Recirculation (EGR) or Selective Catalytic Reduction and Urea technology (SCR and Urea) measures. Vehicle retrofitting has been gradually implemented in the UK over recent years. Grants have been awarded in the UK (from the Energy Savings Trust and Transport Energy Clean-Up Programme for retrofitting particulate filters and devices (EGR, SCR) to reduce NO_x emissions. In London, more than 1000 buses have been retrofitted in a Transport for London project with equipment to reduce NO_x emissions. This was in response to calls to retrofit the vehicle fleet in the UK to meet Euro 5 exhaust emission standards. Priority of retrofitting was given to bus routes passing through areas of high NOx concentrations (Air quality news, 2014). The Mayor of London and Transport for London recently announced that they are to expand London's bus retrofit programme with a further 400 vehicles, bringing the total number of buses fitted with a SCR system up to 1,800. A grant from the Department for Transport's Cleaner Vehicle Technology Fund has also been secured to retrofit a London Fire engine with SCR technology (TfL, 2014).

4.3.1 Impacts of the Measure on NO_2 and Potential Effectiveness

EGR systems typically reduce emissions of NO_x by up to 40%, although this depends on the operating conditions and is less effective in urban driving. SCR and Urea technologies have been shown to be much more effective, as Liu *et al*. (2008) found a 50.6% reduction in gaseous NO_x emissions in an experimental laboratory study. Kusaka, (2005) however found a 70-90% NO_x conversion (NO_x conversion is NO_x to N_2 and H_2O) under medium and high load conditions and also showed that NOx conversion exceeds 90% when the catalyst temperature is higher than 530 K in an experimental laboratory study. The difference is listed as being due to the variation in urea doses.

The viability of the implementation of Selective Catalytic Reduction (SCR) on vehicle fleets in the UK has been analysed. (Amec, 2011). This study specifies that at regular operation conditions in the UK, SCR reduces NO_x emissions by 50% to 70% (in London and Edinburgh). Implementing these devices in Pre-Euro and Euro 1 passenger cars would enable them to comply with the Euro 4 and Euro 5 standards, while doing it for Euro III buses would allow vehicle compliance with Euro V standard. However, SCR fitted in the factory on new vehicles is more effective than retrofits. For best performance the engine needs to be controlled and optimised to maintain SCR temperature.

Borillo *et al* (2015) studied the use of the SCR on a diesel engine vehicle with different fuel types and found statistically significant lower NOx emissions with the SCR compared to a vehicle without SCR.

The most recent evidence is available from Carslaw & Priestman (2015) where remote sensing of emissions from vehicles with SCR and SCRT (combines a CRT (Continuously Regenerating Trap) to reduce particle emissions and SCR) were measured in London and Oxford. In both locations the study found large variation in the effectiveness of SCR, from baseline impact to a 90% reduction in emissions of NOx, with greatest reductions where the engine temperature is hotter. In London, over 700 on-road measurements were made of the low NO_2 SCRT system on TfL Euro III retrofitted buses. On average, a reduction in NO_x of 45% compared with similar (bus type, Euro classification and engine) non-SCRT buses was observed. The corresponding reduction in NO_2 emissions was 61%. At a more controlled vehicle test track the SCRT system was shown to effectively reduce emissions of NOx by 77% on average compared with the base bus with no after-treatment, Reductions in NO_x of 90% were shown for the SCR-only system. Emissions of NO_x and NO_2 were shown to increase as the system cooled. In Oxford it was found that bus emissions of NO_x and NO_2 can vary widely even for vehicles nominally using the same after-treatment and identical Euro class (Carslaw & Priestman, 2015). Euro III buses retrofitted with an SCRT showed the lowest NO_x emissions of the bus fleet, though these also had the highest NO_2 emissions with 40% of the NO_x being emitted as NO_2. These NO_x emissions were slightly less than from a Euro V bus.

4.3.2 Wider Impacts and Unintended Consequences

Without regular periods of sustained, higher engine power operation (i.e. motorway driving/speeds) the conditions needed for Diesel Particle Filters (DPFs) to regenerate are absent. DPF faults are therefore common in taxis and cars with high levels of stop/start urban driving. These faults are often expensive to rectify and has led some vehicle owners to remove the DPF.

Urban drive cycles are considered problematic in generating sufficiently high exhaust temperatures for the correct functioning of SCR units, which usually require exhaust gases to exceed 240°C for at least 30% of the time (Johnson. 2006). There are additional concerns regarding the available space for installing such devices and it is unlikely for a vehicle that already has a DPF unit installed to host a SCR device as well. Suppliers suggest that whether or not a HGV can technically be retrofitted with SCR is extremely variable and is resolved on a case-by-case basis (Amec, 2011).

Borillo *et al* (2015) found that when Low Sulphur Diesel (LSD) and Ultra LSD fuels were used, the SCR system also significantly reduced emissions of compounds with high photochemical ozone creation potential, such as formaldehyde. However, for all tested fuels, the SCR system produced significantly higher emissions of N_2O. In the case of LSD, the NH_3 emissions were elevated, and in the case of ULSD, the non-methane hydrocarbon (NMHC) and total hydrocarbon of diesel (HCD) emissions were significantly higher with the SCR after treatment.

Low volume SCR units cost between £11,000 to 12,000 (prices quoted during 2013/14 DfT CBTF Programme) with combined SCR & particle traps costing £12,500 to £14,000. There is no fuel increase associated with SCR systems, however, there is a fuel impediment of 1-3% (TfL observation) due to back pressure associated with the particle trap on a SCRT system. A correctly working SCR system will require dosing with AdBlue at 5% per volume of fuel. AdBlue currently costs 23 pence per litre. For a double deck bus with annual mileage of 70,000 miles, the additional cost of AdBlue over 5 years is estimated at £4,312.50. The increase in maintenance and certification is estimated at £1,000 per annum.

A key issue with Euro V buses fitted with SCR is that the operational temperature is not optimised for urban running. SCR units do not perform well when speed drops below 50km per hour and AdBlue dosing drops below 5% per volume of fuel. Euro V buses can be retrofitted with Thermal Management Units (TMU) that increase the operational temperature at urban speeds by causing managed back pressure, thus increasing AdBlue dosing towards 5%. TMU cost circa £4,000 per unit.

Amec (2011) found that the costs of SCR retrofit equipment may exceed the projected residual values of pre Euro IV vehicles that were considered for retrofit. This implies that the number of owners and operators that may choose to retrofit vehicles to comply with a LEZ or any form of access restriction based on standards, may be lower than those who choose to purchase new or newer vehicles.

There has been reluctance on the part of bus companies to retrofit buses with SCR due to increased operational costs, particularly where a SCRT is used. Even where DfT funding has been made available through the Clean Bus/Vehicle Technology Fund Programme, take up has been low. A key tension is whether bus emission investment is aimed at Euro III buses with a few operational years left or whether it is concentrated on newer, cleaner buses.

4.3.3 Implementation Success Criteria

Retrofitting a vehicle with pollution control equipment is a complex engineering procedure which must be performed with care. An evidence review and case studies indicate the following principles for any retrofit project (adapted from Wagner & Rutherford, 2013):

1. *Establish rigorous verification systems to ensure effectiveness*

   Maximum real world emission reductions will be achieved only with technologies whose effectiveness have been verified or certified by an official authority.

2. *Conduct pilot projects to build capacity and test the suitability of off-the-shelf technologies for local conditions*

   Whether a local authority is considering a voluntary or mandatory retrofit scheme, smaller scale pilot projects can be an important first step toward an effective scheme. Pilot projects help educate stakeholders on the key issues associated with installing and monitoring the performance of retrofit technologies while providing a means to determine whether off-the-shelf technologies are appropriate to local conditions. Vehicles for pilot projects are typically from public or privately contracted fleets that offer decentralised procurement maintenance and fuelling systems.

3. *Domestic supply must match local demand*

   International experience suggests that the majority of retrofits adopted under a new scheme will ultimately be purchased from domestic manufacturers particularly when public subsidies *are involved. It is therefore crucial that the domestic supply matches local demand. Government agencies interested in retrofit schemes may therefore need to directly foster domestic manufacturing capacity by actively engaging with local manufacturers. This role is best played by the national regulatory authority overseeing vehicle manufacture.*

4. *Retrofit subsidies may be necessary, both to ensure participation in voluntary schemes but also to lessen the impact of mandatory schemes on economically disadvantaged populations*

   As with scrappage schemes, complementary pricing mechanisms for retrofitting may increase uptake. Incentives are particularly important for retrofits because, in contrast to scrappage, the driver gains no real benefit for installing the equipment other than the continued right to use the vehicle. Incentives may take the form of direct subsidies, tax breaks or low interest loans for equipment purchase. These incentives will be particuarly important in securing participation of capital constrained owner-operators in retrofit voluntary schemes and limiting the adverse economic effects of mandatory schemes on those stakeholders.

5. *Enforcement and follow up is important*

   Continued engagement with operators and manufacturers may be necessary to verify that the retrofits remain installed and continue to work properly throughout the vehicle's lifetime. While it is possible to test the actual emissions of vehicles once they are in service, more practical periodic inspection on-road, on-site or in areas where HDVs typically gather (eg regional distribution centres) may offer insights into whether retrofits are installed and maintained properly.

5 Incentivise the uptake of low emission vehicles and fuels

Box 8: Key Findings: Incentivising the uptake of low emission vehicles and fuels

- Several efficient vehicle technologies are commercially available such as hybrid, natural gas or electric vehicles.
- CNG vehicles with a 3 way catalyst deliver the lowest NO_x emissions compared to other fuel/technologies
- CNG also delivers low PM and CO_2 emissions compared to other fuels
- Plug-in hybrid uptake is being encouraged through current Office for Low Emission Vehicles (OLEV) grants
- Full electric vehicles have no associated local emissions but range anxiety, where the driver is concerned about sufficient power to reach their intended destination, is an issue for vehicle owners.

Measures considered earlier in this report, including pricing mechanisms and LEZs can encourage the uptake of low emission vehicles. Other measures focus directly on incentivising the uptake of low emission vehicles e.g. the UK "plug in places" grant scheme to encourage the installation of electric vehicle charging points. The spectrum of alternative fuel vehicles is quite wide ranging, with mild-hybrid, hybrid and plug-in hybrid and Full Electric Vehicle (FEV) powertrain technologies. It is possible that plug-in hybrid vehicles could operate in FEV mode in environmentally sensitive areas triggered by geo-fencing technology in the future. Alternative fuels to the conventional petrol and diesel include Compressed Natural Gas (CNG), Liquefied Natural Gas (LNG), biodiesel and ethanol. This section considers the impact of low emission vehicle and fuel uptake on NO_2 concentrations.

5.1 Natural Gas vehicle technology

The technology of natural gas vehicles (NGV's) is well established. There are now some 16.7 million natural gas vehicles operating worldwide, with significant fleets in China, Iran, Pakistan, India, the US and Europe. The largest deployment in terms of heavy duty vehicles has been in urban buses.

Compressed natural gas (CNG) buses have been deployed in many cities in the US and across Europe to improve air quality.

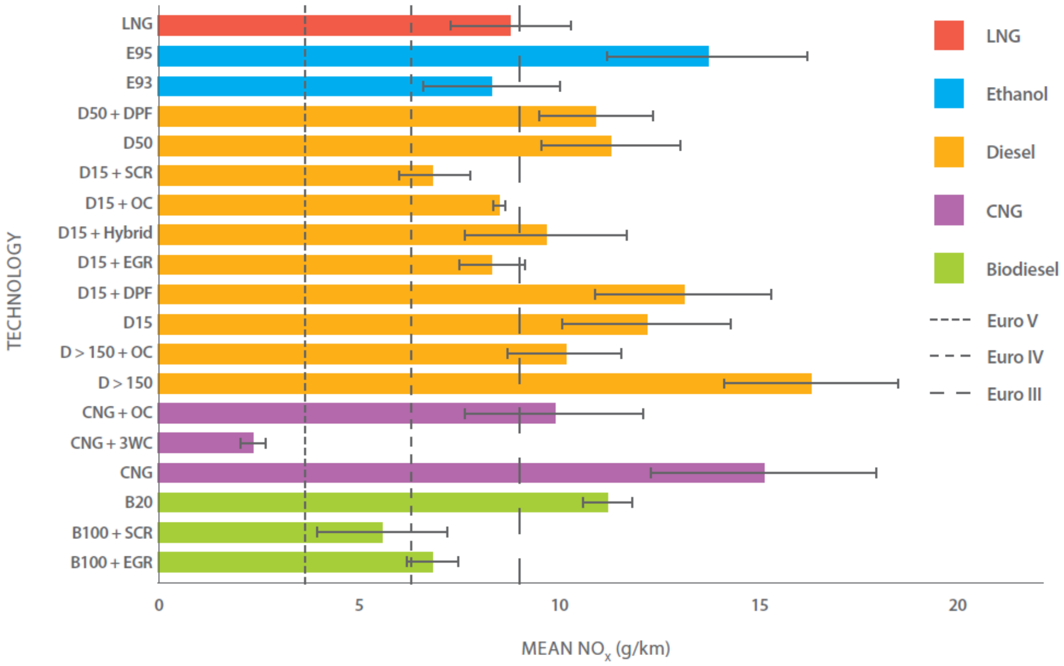
There are currently around 700 natural gas vehicles in the UK. Industry projections (Freight Transport Association, 2014) suggest that 20% of all HGVs could be either dual fuel or dedicated natural gas by 2020.

There is a risk of fuel leakage with CNG, and there is a consequent potential climate warming impact of leaked methane and from fuel slippage.

5.1.1 Impacts of the Measure on NO_2, and Potential Effectiveness

In a meta–analysis of global data from in-use transit bus emission tests to define ranges of exhaust emissions for fuel and technology combinations (Cooper *et al*, 2012), CNG buses fitted with a 3-way catalyst (TWC) were found to be the lowest NO_x emitters as shown in Figure 2.

Figure 2 Mean for NOx Emissions by Technology (g/km) (from Cooper *et al,* 2012 www.embarq.org)



Manufacturers' emission test results given for emissions certification for the Mercedes Econic lean burn gas engine, the latest stoichiometric TWC engines from Iveco.MAN, Scania and the dual fuel system from Hardstaff were compared with the Euro IV, V and VI Euro standards. NOx emissions from the lean burn and dual fuel technology are capable of meeting the Euro V standard, and those from the stoichiometric engines can meet Euro VI standards. This underlines the recent move away from lean burn CNG technology to stoichiometric and TWC in order to more easily meet the Euro VI emission standard.

Real-world emission tests carried out by VTT, Finland (Murtonen *et al*, 2009), on Euro V diesel and CNG buses showed that NO_x emissions were up to 90% lower for CNG compared to diesel.

In a recent study of real-world emission testing of Euro III, IV & V diesel and Euro V CNG (lean burn with OC) buses in China fitted with SCR (Jiadong Guo *et al*, 2014), the NO_x reduction efficiencies of the SCR systems for CNG buses were higher because of the high exhaust temperature and high NO_2/NO_x ratio, whereas the efficiencies for diesel buses were lower. This resulted in extremely low NO_x emissions from CNG buses.

While there is little in the way of real-world emissions test results available for Euro VI natural gas buses, test cycle data published by Scania indicates that Euro VI CNG buses will continue to outperform comparable diesel buses in terms of NO_x emissions.

Further work is also needed to identify real-world emissions of NOx from dual fuel (diesel/natural gas) trucks. While test data from Hardstaff indicates that NOx emissions are reduced compared with dedicated diesel, test data from California on Euro III trucks (UK Biomethane Toolkit, 2009, Cenex) indicated that there was a marginal increase in NO_x. This was thought to be due to the fact that early dual fuel vehicles were optimised to run primarily on diesel. PEMS testing of dual fuel trucks in the UK is currently being carried out as part of the TSB Low Carbon Truck Trial Programme with results expected shortly (see www.gasvehiclehub.org).

5.1.2 Wider Impacts and Unintended Consequences

Many studies have shown that CNG buses have significantly lower particulate emissions compared with diesel buses fitted with DPF. Jiadong Guo *et al* (2014) reported that lean burn CNG buses had both significantly lower particle numbers and particle mass compared with diesel. Murtonen *et al* (2009) reported up to a 90% reduction in PM for Euro V CNG buses compared with diesel Euro V buses

Natural gas vehicles (both CNG and LNG) are acknowledged to have marginal (circa 10-15%) CO_2 benefits over diesel vehicles, however, this can vary depending on the supply chain and delivery pipe pressure system. Where biomethane is substituted for natural gas the CO_2 benefits can range from 60-80% depending on the source of biomethane.

LowCVP report that well-to-wheel CO_2 savings of up to 65% can be achieved by vehicles using biomethane in urban and motorway drive cycles. Up to 16% CO_2 savings can be achieved over similar cycles using natural gas.

Typically, stoichiometric gas engines have a thermal efficiency of 35/36% compared with a diesel efficiency of 43%. Scania report that their Euro VI gas engine has a thermal efficiency of 40%, indicating that well to wheel CO_2 emissions for new gas vehicles could improve further.

Some care is needed in looking at gas losses in certain delivery systems. LNG can boil off and has potential for methane losses which can be significant. Technology is improving i.e. with the use of LNCNG systems (where boil off is diverted into compressed tanks) and nitrogen blankets to prevent boil off. CNG systems do not have significant gas losses.

Studies by Embarq, Jiadong Guo *et al* (2014) have reported that there can be a marginal increase in CO and THC emissions with CNG buses compared with diesel.

5.1.3 Implementation Success Criteria

The key implementation success criteria centres around costs, not just capital purchase price but the cost of infrastructure installation. It may be expected that operators would shift to gas technology once they can see that gas fuel prices are lower than diesel, and that over the lifetime of the vehicle that is cheaper, despite a higher purchase price for gas engine technology.

Manufacturers' data from Mercedes, Iveco, Man, Volvo, VW etc. indicate that the estimated marginal cost of a range of CNG/LNG vehicles is in the region of:

- Car derived van - £1,500
- Panel Van - £4,000 - £6,000
- Small- Medium HGV – £15,000 - £25,000;
- Large HGV – £35,000;
- Small bus – £15,000;
- Large bus – £30,000.

From data sourced from the DfT Green Bus Fund Programme, the Scania Euro 5 CNG bus (single deck) cost £32,000 more than its diesel equivalent (DfT 2015).

It is likely that, due to the increased marginal cost of Euro VI diesel vehicles compared with Euro V, CNG and LNG vehicles will see a marginal reduction in price difference with diesel vehicles in the order of 5 -10%.

Reading Buses (J Bickerton, 2014) reported that their Scania Euro V single deck buses cost 13p per mile to run compared with 26p per mile for the equivalent diesel bus. Buses running on biomethane qualify as a Low Carbon Emission Bus (LCEB) and receive an additional 6p per km BSOG subsidy.

Discussions are currently taking place within the LowCVP Bus Working Group as to potential changes in LCEB BSOG subsidies which may make the use of biomethane more attractive.

The cost benefits of gas vehicles over diesel depend on both gas and diesel price fluctuations and also changes in fuel duty.

The Government announced in the Autumn Budget 2013 that fuel duty for methane would not increase from 24.7p/kg for the following 10 years. A review is due in 2017 to see whether the differential with diesel duty, particularly for biomethane, should be increased.

Key barriers for the uptake of gas vehicles include vehicle and refuelling infrastructure availability. While the range of gas vehicles on the continent is comparable to conventional fuelled vehicles, the availability of right hand drive models remains limited, however, this is increasing. LDV and HDV options are increasing rapidly, however, there are no OEM passenger car offerings yet in the UK

The number of gas refuelling stations is also increasing rapidly, however, they are predominantly depot based with some offering 3rd party access. The only public refuelling station is based at DIRFT on the M1 (for station network see www.gasvehiclehub.org).

The cost of installing gas stations depends on volume of gas compression required and whether CNG or LNG is used. LNG stations that utilise over ground delivery are generally cheaper to install (circa £150,000 to £500,000) whereas CNG station costs depend on the type of gas pipe source/level of compression required and volume of gas needed. With CNG, it is preferable to source from a medium/intermediate or high pressure (LTS) main which reduces compression costs. Connection to an LTS main is expensive and can cost £300,000 plus.

The length of the payback period to cover the cost of a station is important. For example, Reading Buses reported that their CNG station cost £1m and will be paid back in 7 years. The station will serve up to 50 buses.

Many gas supply companies are now willing to install and operate stations at their own cost and charge a ‘wet lease’ nozzle price for gas. This is increasingly attractive to vehicle operators without the know-how and capital to install and operate a station. The price quoted by ENN (www.enn.cn) for nozzle supplied gas (station provided by ENN) is 81.8p/kg (CNG) and 88.8p/kg (LNG) ex VAT.

5.2 Hybrid Electric Vehicles

Hybrid electric powertrains pair a petrol or diesel internal combustion engine with an electric motor that is powered by on-board batteries which are charged by either regenerative braking or the engine. Diesel hybrids are used for heavy duty vehicles while petrol hybrids are for light duty vehicles. Due to the reduced combustion engine, hybrids produce lower emissions than a conventional vehicle. While this technology is widely available for passenger cars, in the UK the uptake of hybrid passenger cars is low to moderate (0.3% of the total vehicle fleet) and the uptake of hybrid LGVs is low.

During 2014 the government ran a Plug-in Car and Van Grant scheme. This scheme covers a maximum of £5,000 off an electric car and £8,000 off the price of an electric van provided they are a model from a specified list (OLEV[7] commitment in September 2013). As of 30 June 2014 the number of plug in grant claims was 11260 for cars and 637 for vans. These grants sit under the wider umbrella of plug-in vehicle charge point grants. In April 2014 OLEV committed to retain the £5,000 off a plug in electric car until 2017 (or until 50,000 vehicles have been purchased, whichever the soonest).

5.2.1 Impacts of the Measure on NO_2 and Potential Effectiveness

Different experiments and modelling exercises have intended to quantify the effect of deploying HEV technologies on different vehicle types in the UK.

Real-world back-to-back trials in London (2006-2010) involving four bus suppliers, six series- and parallel-hybrids, single- and double-deck models, using Euro IV+SCR and V engines suggest that actual NO_x and PM emissions vary widely depending on vehicle drive-train, route, and other factors. The range of NO_x reduction ranges from zero to 32%. There did not seem to be any apparent discernible correlation with hybrid type (series or parallel).

[7] OLEV = Office for Low Emission Vehicles

The U.S. evaluation study dating from 2005-2006 compared 10 articulated New Flyer DE60LF hybrid buses (18m, 30.4t GVW) with conventional diesel bus equivalents in Seattle, Washington. The results showed that the Caterpillar C9 (8.8L) MY2004 powered parallel hybrids (approx. Euro IV equivalent) emitted between 18% and 39% less NO_x (depending on route), and 51%-97% fewer particulates. Another US emission testing study in 2005 involving 12m diesel-hybrid buses and the Orion VII (Gen I) low floor buses equipped with BAE Systems' HybriDrive propulsion system. NO_x emissions from the hybrid buses were lower than those from a conventional diesel baseline (with DPF and using 30ppm Ultra Low Sulphur Diesel) by 66% (2.79 vs. 0.94 g/mile). Particulates were reported as the same.

The indicative emissions for hybridised heavy-duty vehicles (assuming use of Ultra Low Sulphur Diesel in all cases) have been given as follows:

- Euro III baseline (no DPF): Hybrids reduce NO_x by 30%
- Euro IV baseline (EGR, no DPF): Hybrids reduce NO_x by 10%
- Euro V baseline (EGR, SCR): Hybrid NO_x equivalent to Euro V

5.2.2 Wider Impacts and Unintended Consequences

The aforementioned tests of a double-decker hybrid bus in the UK on a simulated London route found a 33% reduction in PM emissions compared to a Euro IV Ultra Low Sulphur Diesel (ULSD) baseline, as well as significant reductions in carbon monoxide, total hydrocarbons and drive-by noise (5dBA reduction).

The indicative emissions for hybridised heavy-duty vehicles (assuming use of Ultra Low Sulphur Diesel in all cases) have been given as follows:

- Euro III baseline (no DPF): Hybrids reduce PM by 60%
- Euro IV baseline (EGR, no DPF): Hybrids reduce PM by 20%
- Euro V baseline (EGR, SCR): Hybrid PM equivalent to Euro V

5.2.3 Implementation Success Criteria

Hybrid vehicles and powertrains are well suited to urban driving conditions. Petrol electric hybrid cars have been the norm as smaller lighter petrol engines can be used. Petrol also burns more cleanly than diesel, with three-way catalytic converter technology able to reliably reduce emissions of local air quality pollutants such as CO and NO_x to a low level.

The capital cost of hybrids is generally higher than conventional vehicles. The limitation of charging points to gain the benefit of electric driving has been a barrier but in reality most hybrid owners charge at home or at work.

5.3 Full Electric vehicles (FEV)

The uptake of electric vehicles in the UK remains low, but according to a report by the Department for Transport, it should increase in the long term (DfT, 2008). This report examined several scenarios including different uptake rates of electric vehicles and concluded that higher uptake correlates with existing charging infrastructure, available incentives as well as changes in purchase costs.

5.3.1 Impacts of the Measure on NO_2 and potential effectiveness

Electric vehicles produce no air quality pollutant exhaust emissions (although the production of the electricity elsewhere has some environmental impact, in the same way as the production of petrol and diesel fuels).

5.3.2 Wider Impacts and Unintended Consequences

The introduction of more electric vehicles would increase demand on power stations; incentives to increase the uptake of electric vehicles should be managed within the medium to long term plans for electricity supply.

5.3.3 Implementation Success Criteria

As with hybrid electric vehicles, the main trigger for uptake is the low fuel cost, but for FEV the main barrier is range anxiety, where drivers are concerned that battery power may not be sufficient to reach their intended destination: Unlike hybrids, there is no backup petrol or diesel engine when battery charge has been depleted.

6 Conclusions

6.1 Key findings from the literature

The rapid evidence review identified numerous technical and non-technical measures that have been implemented in different cities in Europe and around the world, and whose efficiency in bringing about behavioural changes or emissions abatement has been examined. At this point in time, numerous local authorities throughout the UK have adopted policy packages in an effort to comply with the national air quality objectives for NO_2. In many cases these efforts have not been sufficient or have not achieved the desired outcomes, as demonstrated by the continuous non-attainment of various air quality management zones with such national objectives. It is therefore critical to focus future policy development on those measures that have potential for sustained emissions abatement whilst being cost effective.

The analysis of the different abatement measures suggests that the most cost-effective measures, when considered in terms of delivering air quality objectives are those that specifically target air quality. The benefits of targeted local transport measures for improving air quality highlight that there might be a role for preferential use of locally targeted measures for improving air quality, as opposed to national-based measures. Moreover, the performance of each of these measures in driving compliance with environmental objectives has proven to be extremely site-specific. It does appear that measures have an important degree of effectiveness if targeted at specific urban hot-spots but less effective if applied elsewhere. It has also been suggested that greater overall environmental benefits could be achieved if the different policy approaches are usually larger or city-wide schemes, rather than focused on NO_2 hot-spots such as road junctions. This site-specificity stresses the need of assessing the effectiveness of each measure in its local context and avoiding making assumptions that schemes will transfer and lead to the same benefits. Such analysis should be underpinned by modelling tools that are credible and fit-for-purpose.

A wide case study review by Wagner & Rutherford (2013) concluded the following practices were effective to lower vehicle emissions:

1. Target high emitting vehicles: Characterizing vehicle emissions and identifying high-emitting vehicles through measures such as inspection and maintenance programmes, or Low Emission Zones (LEZs).
2. Use cleaner fuels: Programmes to promote the use of cleaner fuels that lower emissions either directly such as taxation schemes or by facilitating the use of advanced emission control technologies e.g. incentive schemes such as Plug-in Places (section 4.4.2)
3. Scrap older vehicles: Programmes to replace existing high-emitting vehicles with cleaner ones
4. Retrofit high-emitting vehicles: Programmes to reduce in-use emissions by installing after treatment control technologies, replacing the engine, or by reducing aerodynamic drag where significant useful vehicle life remains
5. Employ complementary strategies: Complementary emission reduction programmes, including incentives to increase public transport use and transportation network improvements.

Pricing Mechanisms

Evidence from the literature indicates that the use of taxation instruments by policy makers is an effective tool to drive the preferences of consumers towards specific choices. Although pricing mechanisms that are focussed on the purchase choice of vehicles can take some time to have a significant effect on the fleet (as new vehicle purchases are made infrequently), over time they can have a significant impact. The literature notes that the application of a tax structure across many European Member States to encourage the purchase of low CO_2 emitting vehicles coincided with a large increase in diesel vehicles which have lower CO_2 emissions compared to their petrol counterparts. This measure is viewed as highly effective in supporting the desired climate change policy. The application of taxes is generally considered to be efficient to implement, due to the fact that a tax-collection system is already in place in every country. There were reports of additional benefit gained from increasing public revenue when it is directed to support complementary measures such as improving public transport or transport network improvements. The wider impacts and unintended consequences of any measure to improve air quality are important to consider. There is much evidence in the literature suggesting that the taxation policy to encourage low CO_2 emitting vehicles links to higher emissions of NO_x across Europe. The use of pricing mechanisms can also have social inequality consequences with those of lower incomes being more disadvantaged. For local or regional schemes, such as road tolls, schemes need to be designed with care to discourage pollutant emission displacement where drivers use alternative routes to avoid tolls.

Low emission zones

The literature provides mixed evidence on the effectiveness of LEZs. Holman *et al* (2015) reviewed the effectiveness of LEZs across five Member States in Europe. The evidence presented indicated a neutral impact with the German LEZs that target cars alongside HDVs as monitoring data show only a few percent improvement in long term PM_{10} and NO_2. Where LEZs have been restricted to HDVs, there appears no clear evidence of an impact on pollutant levels. However, Holman *et al* (2015) go on to suggest that there may be a number of confounding factors, including meteorology and as traffic is not a large contributor to PM_{10} so $PM_{2.5}$ may be a more appropriate metric as a key performance indicator.
Malina & Scheffler (2015) also reviewed the effectiveness of German LEZs and found a decrease in urban PM_{10} levels that can be attributed to the introduction of LEZs and that more stringent zones (stage 2 zones) reduce PM_{10} concentrations more than three times as much as stage 1 zones. Ferreria *et al* (2015) reviewed the effectiveness of the Lisbon LEZ and did find a positive impact. In 2013 (after LEZ), there was a 23% reduction in PM_{10} annual average concentration and 12% reduction in NO_2 annual average concentrations, compared with the year 2011 (before LEZ). Although PM_{10} reductions were more significant inside the LEZ area, the same was not valid for NO_2, suggesting that the implementation of such measures was not as effective in reducing NO_2 levels as shown by results in other cities like Berlin. An important conclusion from Fereria *et al* (2015) is that, stricter restriction standards (i.e. higher Euro Standards) should be enforced in the future stages of the Lisbon LEZ in conjunction with a higher effort and investment on LEZ enforcement and this should result in further improvement in air quality. This stems from the fact that NO_x emissions under real driving conditions have not performed according to Euro test conditions. Once real world driving emissions are aligned with test conditions, only then can the true effectiveness of LEZs focussed on NO_x emissions be realised.

The effectiveness of a LEZ depends on the set emission standards, its enforcement degree, the potential number of affected vehicles, its geographic extension, and the pre-LEZ vehicle fleet. The implementation of a LEZ requires coordination with other measures that are likely to be applied in the same policy context in order to direct the response of affected vehicle operators towards a desired outcome. Examples of these additional measures are promoting retrofitting to achieve compliance with emission standards, incentivising the uptake of cleaner vehicle technologies through funding schemes or shifting freight to other transport modes such as railways. In terms of the LEZ strategy itself, it is cost-effective in the sense that it focuses on directly controlling tailpipe emissions of airborne pollutants and not on the driver behaviour patterns that precede such emissions. Successful implementation of LEZs relies on effective communication and awareness campaigns (including proper signalling) and introducing a comprehensive legislative framework that includes enforcement degrees as well as exceptional agreements.

Vehicle scrappage and retrofit

Scrappage schemes aim to reduce overall emissions from the vehicle fleet by targeting those with the worst emission characteristics. Scrappage schemes provide pathways for increasing the rate at which the national vehicle fleet is replaced, therefore improving the aggregate emissions performance. They seek to reduce the contribution of highly-polluting vehicles and replace them ideally with the best available technologies. Furthermore, when the selection of vehicles to be retired is made carefully, the achieved emission reductions can be comparable to the main alternatives for reducing fleet emissions at a reasonable cost. The implementation of scrappage schemes will depend on the amount of vehicles that are to be replaced and on the capacities of the funding body to dispose of the retired vehicles. Scheme design should be carefully considered: One unintended consequence reported in the literature is that those vehicle owners around the threshold (age of vehicle) for the scrappage scheme often retain their vehicle longer than intended to benefit from the scrappage scheme, giving rise to higher emissions. Scrappage actions can be more effective when combined with appropriate taxation/incentives mechanisms that encourage the uptake of alternative fuel or smaller-capacity vehicles (downsizing).

Vehicle technology to reduce emissions is an important measure. Diesel Particulate Filters can be effective in reducing particulate emissions, though it is a problematic technology for vehicles with high urban driving e.g. taxis. Exhaust Gas Recirculation (EGR) and Selective Catalytic Reduction (SCR) are the technologies to reduce NOx emissions from vehicles. Recent studies have shown that the effectiveness of SCR in reducing NOx emissions is mixed. The picture is complicated as there is large variation depending on fuel use, after treatment, Euro Standard, retrofit or not, and the proportion of primary NO_2 emissions also substantially varies. In terms of vehicle retrofit to reduce PM, they are deemed a cost effective means of reducing emissions from HDVs with expensive customized chassis or vehicles with long useful lifetimes. Retrofits may not always be appropriate to all HDVs due to cost, space and mounting constraints. For smaller vehicles with shorter useful lifetimes vehicle scrappage may be preferable. Robust verification systems which match emission control devices to engine type are crucial to ensuring retrofits reduce emissions for the remainder of the vehicle lifetime.

Uptake of Low Emission Vehicles

The promotion of low emission vehicles (e.g. with grants, fiscal incentives, labelling schemes) is a technology ‘fix’. Replacing conventional vehicles with low emission vehicles can generate significant emission and air quality benefits if taken up substantially. However, such measures are not always as effective as expected due to low up take, and many of the alternative technologies are still proving costly. They also do not provide the additional local benefits such as reduced congestion or increased levels of physical activity as some other measures provide. However, at the national level they can provide economic benefits in terms of the development, production and servicing of new vehicle technologies.

Complementary measures

In addition to direct vehicle or technology-based emission reduction strategies, reviews of best practice considered the importance of a variety of complementary measures to reduce emissions from vehicles. Traffic management and access control measures (such as vehicle restricted areas and parking management) physically reduce or remove the source of the air pollution problem. As such they can be very effective and when combined with redevelopment of an area, they can have wider quality of place and economic benefits. However, they can be expensive to implement and because of their restrictive nature can be politically unpopular if not handled sensitively with considerable consultation and engagement.

Demand management measures and measures to encourage shift away from single person car use to other transport modes (walk, cycle, bus, train) can be very cost effective and can have a wide range of benefits from reduced congestion, improved air quality, reduced carbon emissions and increased levels of physical activity. However, travelling attitudes and habits are often very deep rooted and can be hard to change; comprehensive packages of measures which include a focus on information on travel options e.g. personalised travel planning or eco-driving can help to address this. However, the emissions benefit of such information campaigns may tail off over time. Also, although significant impacts in terms of travel behaviour changes have been seen, directly related improvements in air quality have not always been observed. In some cases NO_2 concentration benefits may have been too small to perceive.

Concluding remarks

These measures are not mutually exclusive: studies show that transport interventions are often combined in the aim of achieving a greater impact. For example a programme aimed at encouraging drivers to reconsider their journeys and choice of vehicles can also be used to promote low emission vehicles; a bus quality partnership may generate improvements in overall bus services, assisting shift to an alternative mode of travel, as well potentially improving the emission standards of the buses. Most measures on their own may only generate a small reduction in road vehicle emissions, based on the assessment of local measures implemented in the UK as reported in Local Authority Action Plans and at national and zonal level across Member States in national and local air quality plans. The evidence suggests that greater reductions in NO_x and improvements in air quality may occur when a number of measures are integrated and packaged together. For example, a low emission zone designed to target the higher polluting vehicles can be supported by a package of complementary measures. Such complementary measures can include: improvements in walking, cycle, bus and train facilities; traffic management and pricing mechanisms (to discourage, for example, zone peripheral parking, and peripheral cut through routes); and incentives to encourage uptake to meet vehicle emission compliance such as retrofit or scrappage schemes. If designed appropriately, such measures not only reduce air pollutant emissions but can also provide climate change benefits as well as wider benefits such as noise reduction, congestion alleviation and economic development.

6.2 Gaps in evidence on the effectiveness of policy measures

Lack of data on quantifiable effects of measures

Evidence in the literature on robust quantifiable effect of measures was poor; both the amount of evidence was low and the robustness of that evidence was at times questioned.

Analysis of air pollution concentration and economic data, pre- and post a scheme implementation. This is of course important information to determine cost-effectiveness, but the results are rarely presented with some acknowledgement of the uncertainty in the result. Confounding effects were not always considered, for example, meteorological effects on pollution levels, and economic effects which can impact vehicle use, purchases, and hence emissions. The inclusion of an economic assessment to support the evaluation of policies to reduce air pollution was rarely found in the literature. Conducting future impact and cost/benefit evaluations with reliable data is paramount for implementing cost-effective policies that bring about optimal pollutant abatement levels.

Assessments using vehicle emission models and dispersion models. There are limitations of the different models, and in particular emission factors used to assess measures in older publications may not result in the same impact if calculated using current emission factors. Where various models are used, it is unclear how transferable impacts to other locations are.

Very few studies reported results from before and after measures were implemented or compared results between areas with measures and areas without measures. Many papers reported predictive impacts using models for policy scenario analysis which is less useful to determine real world measure effectiveness.

Lack of data on effectiveness of combined measures

There is sparse data available on the uptake of measures studied over a timeframe of announcement of the policy, initial implementation and full implementation. One exception is that there is good evidence available on congestion charging schemes, which does give valuable pointers especially about the need for a detailed communications plan and complementary measures. Numerous LEZ feasibility studies have been undertaken in the UK but there are evidence gaps in the likely uptake with general assumptions being made. There is little evidence to understand the public acceptability of measures or the uptake of travel behaviours should a measure be implemented which may differ across regions and cities. Gaining this understanding is important to build a set of complementary measures that would increase the chances of a successful package of measures. In addition, while it is evident that many municipalities and authorities across Europe implement a package of measures to improve air quality, no analysis was found in the literature on the optimum combination of measures.

In general, it is challenging to assess the effects of specific policies on NO_2 concentrations following implementation because of various confounding effects, including the influence of meteorology or atmospheric chemistry and changes in emissions resulting from other policy measures. More research and analysis is needed on air pollution concentrations pre- and post- implementation of measures to firm up the evidence base correlating take-up with impacts.

7 References

2008. Directive 2008/50/EC of the European Parliament and of the Council of 21st May 2008 on ambient air quality and cleaner air for Europe *Official Journal of the European Union,* L 152**,** 1-44.

2009. Directive 2009/33/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of clean and energy-efficient road transport vehicles. *Official Journal of the European Union,* L 120**,** 5-12.

ACERO, J. A., SIMON, A., PADRO, A. & SANTA COLOMA, O. 2012. Impact of local urban design and traffic restrictions on air quality in a medium-sized town. *Environ Technol,* 33**,** 2467-77.

AEA, TNO & CE DELFT 2012. Development of a better understanding of the scale of co-benefits associated with transport sector GHG reduction policies. Available: http://www.eutransportghg2050.eu/cms/assets/Uploads/Reports/EU-Transport-GHG-2050-II-Task-1-FINAL-12Jul12.pdf [Accessed 18 December 2013].

AIR QUALITY NEWS 2014. Available: www.airqualitynews.com/2014/07/25/over-1000-london-buses-retrofitted-to-combat-nox/ [Accessed Oct 2014].

AIR QUALITY NEWS 2015. Available: http://www.airqualitynews.com/2015/02/03/oxford-council-welcomes-air-quality-impact-of-lez/ [Accessed May 2015].

ALBERT, G. & GLANZER, Y. 2014. The usefulness of pollution examinations of on-road vehicles—The case of Jerusalem. *Transport Policy,* 35**,** 100-104.

ALDRED, R. & TEPE, D. 2011. Framing scrappage in Germany and the UK: from climate discourse to recession talk? *Journal of Transport Geography.*19**,** 1563-1569.

ALKEMADE, U. G. & SCHUMANN, B. 2006. Engines and exhaust after treatment systems for future automotive applications. *Solid State Ionics,* 177**,** 2291-2296.

ALLEN, J. & BROWNE, M. 2010. Considering the relationship between freight transport and urban form. Transport Studies Department, University of Westminster. Available: http://www.greenlogistics.org/themesandoutputs/wm9/downloads/Freight%20transport%20and%20urban%20form%20Final%20September%202010.pdf.

ALOLAYAN, M. A., BROWN, K. W., EVANS, J. S., BOUHAMRA, W. S. & KOUTRAKIS, P. 2013. Source apportionment of fine particles in Kuwait City. *Sci Total Environ,* 448**,** 14-25.

ALVAREZ, R., SCHLIENGER, P. & WEILENMANN, M. 2010. Effect of hybrid system battery performance on determining CO2 emissions of hybrid electric vehicles in real-world conditions. *Energy Policy,* 38**,** 6919-6925.

ALVAREZ, R. & WEILENMANN, M. 2012. Effect of low ambient temperature on fuel consumption and pollutant and CO2 emissions of hybrid electric vehicles in real-world conditions. *Fuel,* 97**,** 119-124.

AMEC. 23/11/2011 2011. *RE: Defra Study to Investigate the Feasibility of Developing a Certification Scheme for Technology Retrofitted to HDVs to Abate NOx Emissions.*

AMEC 2012a. DEFRA Multi Pollutant Measures Database (MPMD): Extension to 2030. Measure: Downsizing petrol cars.

AMEC 2012b. DEFRA Multi Pollutant Measures Database (MPMD): Extension to 2030. Measure: Replacing pre-Euro 6 buses with electric buses.

AMEC 2012c. DEFRA Multi Pollutant Measures Database (MPMD): Extension to 2030. Measure: Replacing pre-Euro 6 diesel LGVs with electric LGVs.

AMEC 2012d. DEFRA Multi Pollutant Measures Database (MPMD): Extension to 2030. Measure: Replacing pre-Euro 6 petrol and diesel cars with electric cars.

AMEC 2012e. DEFRA Multi Pollutant Measures Database (MPMD): Extension to 2030. Measure: Replacing pre-Euro 6 petrol and diesel cars with hybrids.

AMEC 2012f. DEFRA Multi Pollutant Measures Database (MPMD): Extension to 2030. Measure: Replacing pre-Euro VI buses with hybrid buses.

AMEC 2012g. DEFRA Multi Pollutant Measures Database (MPMD): Extension to 2030. Measure: New hydrogen fuel cell buses instead of new diesel buses.

AMEC 2012h. DEFRA Multipollutant Measures Database (MPMD): Extension to 2030. London, United Kingdom. Available: https://uk-air.defra.gov.uk/assets/documents/reports/cat08/1212100954_31772_MPMD_Draft_Final_Report_for_comment.pdf [Accessed May 2016].

ANDERLOHR, J. M., PIPEREL, A., PIRES DA CRUZ, A., BOUNACEUR, R., BATTIN-LECLERC, F., DAGAUT, P. & MONTAGNE, X. 2009. Influence of EGR compounds on the oxidation of an HCCI-diesel surrogate. *Proceedings of the Combustion Institute.*32**,** 2851-2859.

ANDRESS, D., DAS, S., JOSECK, F. & DEAN NGUYEN, T. 2012. Status of advanced light-duty transportation technologies in the US. *Energy Policy,* 41**,** 348-364.

ANDRESS, D., NGUYEN, T. D. & DAS, S. 2011. Reducing GHG emissions in the United States' transportation sector. *Energy for Sustainable Development,* 15**,** 117-136.

ANYADIKE, N. 2002. 5 - Nickel alloy steels. *In:* ANYADIKE, N. (ed.) *Nickel.* Woodhead Publishing.

APELBAUM, J., LI, Z. & HENSHER, D. A. 2011. A correction framework for improving the robustness of motor vehicle registration data: An Australian application. *Transportation Research Part D: Transport and Environment.*16**,** 562-570.

ARMSTRONG, V. N. 2013. Vessel optimisation for low carbon shipping. *Ocean Engineering.*73**,** 195-207.

ARNOTT, R. & INCI, E. 2006. An integrated model of downtown parking and traffic congestion. *Journal of Urban Economics,* 60**,** 418-442.

ARNOTT, R. & ROWSE, J. 2009. Downtown parking in auto city. *Regional Science and Urban Economics,* 39**,** 1-14.

ARSLAN, O. & KARASAN, O. E. 2013. Cost and emission impacts of virtual power plant formation in plug-in hybrid electric vehicle penetrated networks. *Energy,* 60**,** 116-124.

ASAFU-ADJAYE, J. & MAHADEVAN, R. 2013. Implications of CO2 reduction policies for a high carbon emitting economy. *Energy Economics.*38**,** 32-41.

ATKINSON, R., BARRATT, B., ARMSTRONG, B., ANDERSON, H. R., BEEVERS, S., MUDWAY, I., GREEN, D., DERWENT, R. G., WILKINSON, P., TONNE, C. & KELLY, F. 2009. The impact of the congestion charging scheme on ambient air pollution concentrations in London. *Atmospheric Environment.*43.

ATTARD, M. & ENOCH, M. 2011. Policy transfer and the introduction of road pricing in Valletta, Malta. *Transport Policy.*18**,** 544-553.

ATTARD, M. & ISON, S. The effects of road user charges in the context of weak parking policies: The case of Malta. *Case Studies on Transport Policy*.

ATTARD, M. & ISON, S. 2014. The effects of road user charges in the context of weak parking policies: The case of Malta. *Case Studies on Transport Policy.*

AVADIKYAN, A. & LLERENA, P. 2010. A real options reasoning approach to hybrid vehicle investments. *Technological Forecasting and Social Change,* 77**,** 649-661.

AXSEN, J., KURANI, K. S., MCCARTHY, R. & YANG, C. 2011. Plug-in hybrid vehicle GHG impacts in California: Integrating consumer-informed recharge profiles with an electricity-dispatch model. *Energy Policy,* 39**,** 1617-1629.

BAHARIN, N. & ABDULLAH, T. A. R. T. 2013. Challenges of PHEV Penetration to the Residential Network in Malaysia. *Procedia Technology,* 11**,** 359-365.

BANDEIRA, J., COELHO, M., PIMENTEL, M. & KHATTAK, A. 2012. Impact of Intercity Tolls in Portugal – An Environmental Perspective. *Procedia - Social and Behavioral Sciences.*48**,** 1174-1183.

BAPTISTA, P., RIBAU, J., BRAVO, J., SILVA, C., ADCOCK, P. & KELLS, A. 2011. Fuel cell hybrid taxi life cycle analysis. *Energy Policy,* 39**,** 4683-4691.

BAPTISTA, P., TOMÁS, M. & SILVA, C. 2010. Plug-in hybrid fuel cell vehicles market penetration scenarios. *International Journal of Hydrogen Energy,* 35**,** 10024-10030.

BAPTISTA, P. C., SILVA, C. M., FARIAS, T. L. & HEYWOOD, J. B. 2012. Energy and environmental impacts of alternative pathways for the Portuguese road transportation sector. *Energy Policy,* 51**,** 802-815.

BAPTISTA, P. C., SILVA, C. M., PEÇAS LOPES, J. A., SOARES, F. J. & ALMEIDA, P. R. 2013. Evaluation of the benefits of the introduction of electricity powered vehicles in an island. *Energy Conversion and Management,* 76**,** 541-553.

BARCELO, M. A., SAEZ, M. & SAURINA, C. 2009. Spatial variability in mortality inequalities, socioeconomic deprivation, and air pollution in small areas of the Barcelona Metropolitan Region, Spain. *Sci Total Environ,* 407**,** 5501-23.

BAR-GERA, H., HELLMAN, F. & PATRIKSSON, M. 2013. Computational precision of traffic equilibria sensitivities in automatic network design and road pricing. *Transportation Research Part B: Methodological,* 57**,** 485-500.

BARIMA, Y. S., ANGAMAN, D. M., N'GOURAN K, P., KOFFI, N. A., KARDEL, F., DE CANNIERE, C. & SAMSON, R. 2014. Assessing atmospheric particulate matter distribution based on Saturation Isothermal Remanent Magnetization of herbaceous and tree leaves in a tropical urban environment. *Sci Total Environ,* 470-471**,** 975-82.

BARNETT, A. G. & KNIBBS, L. D. 2014. Higher fuel prices are associated with lower air pollution levels. *Environment International.*66**,** 88-91.

BARNETT, A. G. & KNIBBS, L. D. 2014. Higher fuel prices are associated with lower air pollution levels. *Environ Int,* 66**,** 88-91.

BARRATT, B. 2013. Low emission zones and other traffic reduction measures. *Presentation to the HEI Annual Conference.*

BARTOCCI, A. & PISANI, M. 2013. “Green” fuel tax on private transportation services and subsidies to electric energy. A model-based assessment for the main European countries. *Energy Economics.*40, Supplement 1**,** S32-S57.

BASTANI, P., HEYWOOD, J. B. & HOPE, C. 2012. The effect of uncertainty on US transport-related GHG emissions and fuel consumption out to 2050. *Transportation Research Part A: Policy and Practice.*46**,** 517-548.

BATSCHEIDER, A., ZAKRZEWSKA, S., HEINRICH, J., TEUNER, C. M., MENN, P., BAUER, C. P., HOFFMANN, U., KOLETZKO, S., LEHMANN, I., HERBARTH, O., VON BERG, A., BERDEL, D., KRAMER, U., SCHAAF, B., WICHMANN, H. E. & LEIDL, R. 2012. Exposure to second-hand smoke and direct healthcare costs in children - results from two German birth cohorts, GINIplus and LISAplus. *BMC Health Serv Res,* 12**,** 344.

BEEVERS, S. & CARSLAW, D. C. 2005. The impact of congestion charging on vehicle emissions in London. *Atmospheric Environment.*39.

BEEVERS, S. D., WESTMORELAND, E., DE JONG, M. C., WILLIAMS, M. L. & CARSLAW, D. C. 2012. Trends in NOx and NO2 emissions from road traffic in Great Britain. *Atmospheric Environment,* 54**,** 107-116.

BENDOR, T. & FORD, A. 2006. Simulating a combination of feebates and scrappage incentives to reduce automobile emissions. *Energy.*31**,** 1197-1214.

BEN-ELIA, E. & ETTEMA, D. 2009. Carrots versus sticks: Rewarding commuters for avoiding the rush-hour—a study of willingness to participate. *Transport Policy.*16**,** 68-76.

BEROUD, B., CLAVEL, R. & LE VINE, S. 2010. Perspectives on the growing market for public bicycles: Focus on France and the United Kingdom. Available: http://trid.trb.org/view.aspx?id=1113180.

BICKERTON, J. ADBA UK Gas & Biomethane Vehicle Conference 2014.

BLACKMAN, A., OSAKWE, R. & ALPIZAR, F. 2010. Fuel tax incidence in developing countries: The case of Costa Rica. *Energy Policy.*38**,** 2208-2215.

BLAZQUEZ, C. A., BEGHELLI, A. & MENESES, V. P. 2012. A novel methodology for determining low-cost fine particulate matter street sweeping routes. *J Air Waste Manag Assoc,* 62**,** 242-51.

BLOOMBERG, M. R. & AGGARWALA, R. T. 2008. Think locally, act globally: how curbing global warming emissions can improve local public health. *Am J Prev Med,* 35**,** 414-23.

BOOGAARD, H., JANSSEN, N. A., FISCHER, P. H., KOS, G. P., WEIJERS, E. P., CASSEE, F. R., VAN DER ZEE, S. C., DE HARTOG, J. J., MELIEFSTE, K., WANG, M., BRUNEKREEF, B. & HOEK, G. 2012. Impact of low emission zones and local traffic policies on ambient air pollution concentrations. *Sci Total Environ.*435-436**,** 132-40.

BOOGAARD, H., JANSSEN, N. A., FISCHER, P. H., KOS, G. P. A., WEIJERS, E. P., CASSEE, F. R., ZEE, S. C. V. D., HARTOG, J. J. D., MELIEFSTE, K., WANG, M., BRUNEKREEF, B. & HOEK, G. 2012. Impact of Low Emission Zones and Local Traffic Polices on Ambient Air Pollution Concentrations. *Science of the Total Environment,* 435-436**,** 132-140.

BORILLO, G. C., TADANO, Y. S., GODOI, A. F., SANTANA, S. S., WERONKA, F. M., PENTEADO NETO, R. A., REMPEL, D., YAMAMOTO, C. I., POTGIETER-VERMAAK, S., POTGIETER, J. H. & GODOI, R. H. 2015. Effectiveness of selective catalytic reduction systems on reducing gaseous emissions from an engine using diesel and biodiesel blends. *Environ Sci Technol,* 49**,** 3246-51.

BRAND, C., ANABLE, J. & TRAN, M. 2013. Accelerating the transformation to a low carbon passenger transport system: The role of car purchase taxes, feebates, road taxes and scrappage incentives in the UK. *Transportation Research Part A: Policy and Practice.*49**,** 132-148.

BRAND, C., ANABLE, J. & TRAN, M. 2013. Accelerating the transformation to a low carbon passenger transport system: The role of car purchase taxes, feebates, road taxes and scrappage incentives in the UK. *Transportation Research Part A: Policy and Practice.*49**,** 132-148.

BRANDT, S. J., PEREZ, L., KUNZLI, N., LURMANN, F. & MCCONNELL, R. 2012. Costs of childhood asthma due to traffic-related pollution in two California communities. *Eur Respir J,* 40**,** 363-70.

BROUSSELY, M. 2007. Chapter 4 - Traction Batteries. EV and HEV. *In:* PISTOIA, M. B. (ed.) *Industrial Applications of Batteries.* Amsterdam: Elsevier.

BROUWER, A. S., KURAMOCHI, T., VAN DEN BROEK, M. & FAAIJ, A. 2013. Fulfilling the electricity demand of electric vehicles in the long term future: An evaluation of centralized and decentralized power supply systems. *Applied Energy,* 107**,** 33-51.

BUKA, I., KORANTENG, S. & OSORNIO-VARGAS, A. R. 2006. The effects of air pollution on the health of children. *Paediatr Child Health,* 11**,** 513-6.

BURBANK JR, W., WITMER, D. D. & HOLCOMB, F. 2009. Model of a novel pressurized solid oxide fuel cell gas turbine hybrid engine. *Journal of Power Sources,* 193**,** 656-664.

BUREAU, B. & GLACHANT, M. 2008. Distributional effects of road pricing: Assessment of nine scenarios for Paris. *Transportation Research Part A: Policy and Practice.*42**,** 994-1007.

CABINET OFFICE 2009. The wider costs of transport in English urban areas in 2009. UK. Available: http://webarchive.nationalarchives.gov.uk/+/http:/www.cabinetoffice.gov.uk/media/307739/wider-costs-transport.pdf [Accessed May 2016].

CALIFORNIA AIR RESOURCES BOARD 2013. Enhanced Fleet Modernization Program Assessment. Available:

http://www.arb.ca.gov/msprog/aqip/EFMP_Update_Staff_Report_November_2013.pdf [Accessed May 2016].

CAMPAIGN FOR BETTER TRANSPORT 2013. The M6 Toll – Ten years on. Available: http://www.bettertransport.org.uk/sites/default/files/research-files/M6_Toll_Ten_Years_briefing_Dec2013_FINAL.pdf.

CAMPANARI, S., MANZOLINI, G. & GARCIA DE LA IGLESIA, F. 2009. Energy analysis of electric vehicles using batteries or fuel cells through well-to-wheel driving cycle simulations. *Journal of Power Sources,* 186**,** 464-477.

CAMPBELL, T. & CAMPBELL, A. 2007. Emerging disease burdens and the poor in cities of the developing world. *J Urban Health,* 84**,** i54-64.

CARPLUS 2013. Carplus — rethinking car use. Available: www.carplus.org.uk [Accessed 13 December 2013].

CARSLAW, D. & RHYS-TYLER, G. 2013. Remote sensing of NO2 exhaust emissions from road vehicles. A report for the City of London Corporation and the London Borough of Ealing. Available: https://uk-air.defra.gov.uk/assets/documents/reports/cat05/1307161149_130715_DefraRemoteSensingReport_Final.pdf [Accessed May 2016].

CARSLAW, D. C. & BEEVERS, S. D. 2002. The efficacy of low emission zones in central London as a means of reducing nitrogen dioxide concentrations. *Transportation Research Part D: Transport and Environment.*7**,** 49-64.

CARSLAW, D. C. & PRIESTMAN, M. 2015. Analysis of the 2013 vehicle emission remote sensing campaigns data. *Kings College, London.*

CARSLAW, D. C. & RHYS-TYLER, G. 2013. New insights from comprehensive on-road measurements of NOx, NO2 and NH3 from vehicle emission remote sensing in London, UK. *Atmospheric Environment.*81**,** 339-347.

CAVALCANTI, M., SZKLO, A., MACHADO, G. & AROUCA, M. 2012. Taxation of automobile fuels in Brazil: Does ethanol need tax incentives to be competitive and if so, to what extent can they be justified by the balance of GHG emissions? *Renewable Energy.*37**,** 9-18.

CENEX 2009. Biomethane toolkit: A guide to the production and use of biomethane as a road transport fuel. Available: https://www.americanbiogascouncil.org/pdf/Cenex-biomethane-toolkit-2009.pdf.

CESARONI, G., BOOGAARD, H., JONKERS, S., PORTA, D., BADALONI, C., CATTANI, G., FORASTIERE, F. & HOEK, G. 2012. Health benefits of traffic-related air pollution reduction in different socioeconomic groups: the effect of low-emission zoning in Rome. *Occup Environ Med.*69**,** 133-9.

CHATTERJEE, D., KOČÍ, P., SCHMEIßER, V., MAREK, M., WEIBEL, M. & KRUTZSCH, B. 2010. Modelling of a combined storage and -SCR catalytic system for Diesel exhaust gas aftertreatment. *Catalysis Today.*151**,** 395-409.

CHATTERTON, T. & WILSON, C. 2014. The Four Dimensions of Behaviour framework: A tool for characterising behaviours to help design better interventions. . *Transportation Planning and Technology,* 37**,** 38-61.

CHE, W., ZHENG, J., WANG, S., ZHONG, L. & LAU, A. 2011. Assessment of motor vehicle emission control policies using Model-3/CMAQ model for the Pearl River Delta region, China. *Atmospheric Environment.*45**,** 1740-1751.

CHEN, C. & NIEMEIER, D. 2005. A mass point vehicle scrappage model. *Transportation Research Part B: Methodological.*39**,** 401-415.

CHEN, P. & WANG, J. 2013. Nonlinear and adaptive control of NO/NO2 ratio for improving selective catalytic reduction system performance. *Journal of the Franklin Institute,* 350**,** 1992-2012.

CHEN, X. & ZHAO, J. 2013. Bidding to drive: Car license auction policy in Shanghai and its public acceptance. *Transport Policy.*27**,** 39-52.

CHIU, H. F., TSAI, S. S., CHEN, P. S., LIAO, Y. H., LIOU, S. H., WU, T. N. & YANG, C. Y. 2011. Traffic air pollution and risk of death from gastric cancer in Taiwan: petrol station density as an indicator of air pollutant exposure. *J Toxicol Environ Health A,* 74**,** 1215-24.

CHORUS, C. G., ANNEMA, J. A., MOUTER, N. & VAN WEE, B. 2011. Modeling politicians' preferences for road pricing policies: A regret-based and utilitarian perspective. *Transport Policy.*18**,** 856-861.

CHU, C.-P. & TSAI, M.-T. 2011. A study of an environmental-friendly parking policy. *Transportation Research Part D: Transport and Environment,* 16**,** 87-91.

CIVIL SERVICE 2014. What is a Rapid Evidence Review? . Available: http://webarchive.nationalarchives.gov.uk/20140305122816/http://www.civilservice.gov.uk/networks/gsr/resources-and-guidance/rapid-evidence-assessment/what-is [Accessed September 2014].

CIVITAS 2013. Clean Route Planning for Freight Transport – Utrecht CIVITAS Mimosa project Available: www.civitas-initiative.org [Accessed September 2014].

CLEAN VEHICLES DIRECTIVE 2009. Directive 2009/33/EC of the European Parliament and of the Council on the promotion of clean and energy efficient road transport vehicles.

CLERIDES, S. & ZACHARIADIS, T. 2008. The effect of standards and fuel prices on automobile fuel economy: An international analysis. *Energy Economics.*30**,** 2657-2672.

COMEAP 2015. Statement on the Evidence for the effects of NO2 on health. . Available: https://www.gov.uk/government/publications/nitrogen-dioxide-health-effects-of-exposure [Accessed May 2016].
COMER, B., CORBETT, J. J., HAWKER, J. S., KORFMACHER, K., LEE, E. E., PROKOP, C. & WINEBRAKE, J. J. 2010. Marine vessels as substitutes for heavy-duty trucks in Great Lakes freight transportation. *J Air Waste Manag Assoc,* 60**,** 884-90.
COMISSIONS, E. 2014. Catalogue of air quality measures. Available: https://luft.umweltbundesamt.at/measures [Accessed May 2016].
COOKE, P. N. C. 2010. Recession, Scrappage and Sustainable Recovery. Available: http://www.buckingham.ac.uk/wp-content/uploads/2011/05/pnc-2010-scrappage.pdf [Accessed May 2016].
COOPER E, ARIOLI M, CARRIGAN A & U, J. 2012. Exhaust Emissions of Transit Buses *www.embarq.org*.
COOPER, J., RYLEY, T. & SMYTH, A. 2001. Contemporary lifestyles and the implications for sustainable development policy: lessons from the UK's most car dependent city, Belfast. *Cities.*18**,** 103-113.
CORBETT, J. J., WANG, H. & WINEBRAKE, J. J. 2009. The effectiveness and costs of speed reductions on emissions from international shipping. *Transportation Research Part D: Transport and Environment.*14**,** 593-598.
CORPUZ, G. 2011. An empirical assessment of teleworking using the Sydney Household Travel Survey data. Adelaide: Proceedings of the Australian Transport Research Forum 2011. Available: http://atrf.info/papers/2011/2011_Corpuz.pdf.
CSD 2011. Bicycle-sharing schemes: Enhancing Sustainable Mobility in Urban Areas. Commission on Sustainable Development, United Nations Department of Economic and Social Affairs. Available: http://www.un.org/esa/dsd/resources/res_pdfs/csd-19/Background-Paper8-P.Midgley-Bicycle.pdf [Accessed 13 December 2013].
DALKMANN, H. & BRANNIGAN, C. 2007. 'Transport and Climate Change, Module 5e', Sustainable Transport: A Sourcebook for Policy-makers in Developing Cities. Available: www.gtz.de/de/dokumente/en-transport-and-climate-change-2007.pdf [Accessed 9 April 2013].
DALLMAN, T. R., HARLEY, R.A., KIRCHSETTER, T.W. 2011. Effects of Diesel Particle Filter Retrofits and Accelerated Fleet Turnover on Drayage Truck Emissions at the Port of Oakland. *Environmental Science and Technology.*45**,** 10773–10779.
DANIELLIS, R., ROTARIS, L., MARCUCCI, E. & MASSIANI, J. 2011. An economic, environmental and transport evaluation of the Ecopass scheme in Milan: three years later. SIET Società Italiana di Economia dei Trasporti e della Logistica. Available: https://ideas.repec.org/p/sit/wpaper/11_03.html.
DAVID ROJAS-RUEDA, A. D. N., MARKO TAINIO, MARK J NIEUWENHUIJSEN 2011. The health risks and benefits of cycling in urban environments compared with car use: health impact assessment study. *BMJ.* 8.
DAVIES, L. 2008. The Effect of Driving Restrictions on Air Quality in Mexico City. *Journal of Political Economy.*116.
DAVISON, L., ENOCH, M., RYLEY, T., QUDDUS, M. & WANG, C. 2014. A survey of Demand Responsive Transport in Great Britain. *Transport Policy,* 31**,** 47-54.
DAVISON, L. J. & KNOWLES, R. D. 2006. Bus quality partnerships, modal shift and traffic decongestion. *Journal of Transport Geography.*14**,** 177-194.
DCMS (DEPARTMENT FOR CULTURE MEDIA & SPORT) 2013. Broadband Delivery UK. Available: https://www.gov.uk/broadband-delivery-uk [Accessed 13 December 2013].
DE BORGER, B., MAYERES, I. 2007. Optimal taxation of car ownership, car use and public transport: Insights derived from a discrete choice numerical optimization model. *European Economic Review.*51**,** 1177–1204.
DE BORGER, B. & WUYTS, B. 2011. The tax treatment of company cars, commuting and optimal congestion taxes. *Transportation Research Part B: Methodological,* 45**,** 1527-1544.
DE LARA, M., DE PALMA, A., KILANI, M. & PIPERNO, S. 2013. Congestion pricing and long term urban form: Application to Paris region. *Regional Science and Urban Economics.*43**,** 282-295.
DE LIMA, T. M., KAZAMA, C. M., KOCZULLA, A. R., HIEMSTRA, P. S., MACCHIONE, M., FERNANDES, A. L., SANTOS UDE, P., BUENO-GARCIA, M. L., ZANETTA, D. M., DE ANDRE, C. D., SALDIVA, P. H. & NAKAGAWA, N. K. 2013. pH in exhaled breath condensate and nasal lavage as a biomarker of air pollution-related inflammation in street traffic-controllers and office-workers. *Clinics (Sao Paulo),* 68**,** 1488-94.
DE PALMA, A. & LINDSEY, R. 2006. Modelling and evaluation of road pricing in Paris. *Transport Policy.*13**,** 115-126.
DE RIDDER, K., ADAMEC, V., BANUELOS, A., BRUSE, M., BURGER, M., DAMSGAARD, O., DUFEK, J., HIRSCH, J., LEFEBRE, F., PEREZ-LACORZANA, J. M., THIERRY, A. & WEBER, C. 2004. An integrated methodology to assess the benefits of urban green space. *Sci Total Environ,* 334-335**,** 489-97.
DE VOS, J. & WITLOX, F. 2013. Transportation policy as spatial planning tool; reducing urban sprawl by increasing travel costs and clustering infrastructure and public transportation. *Journal of Transport Geography.*33**,** 117-125.
DEDES, E. K., HUDSON, D. A. & TURNOCK, S. R. 2012. Assessing the potential of hybrid energy technology to

reduce exhaust emissions from global shipping. *Energy Policy,* 40**,** 204-218.
DEFRA 2011. 'Moments of change' as opportunities for influencing behaviour Available: http://www.scpknowledge.eu/sites/default/files/knowledge/attachments/MomentsofChange.pdf [Accessed September 2014].
DEFRA 2013. Air Quality Management Areas Retrieved Available: http://aqma.defra.gov.uk/aqma/home.html [Accessed 18 December 2013].
DEFRA 2014. Air Pollution in the UK 2013 Available: http://uk-air.defra.gov.uk/assets/documents/reports/cat05/1409261329_air_pollution_uk_2013_issue_1.pdf.
DEFRA 2015. Air Quality Plans Available: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/486636/aq-plan-2015-overview-document.pdf [Accessed December 2015].
DEMAIO, P. 2009. Bike-sharing: History, Impacts, Models of Provision, and Future. *Journal of Public Transportation.*12**,** 16.
DEPARTMENT FOR TRANSPORT 2008. Making Personal Travel Planning Work: Practitioners' Guide. Available: http://webarchive.nationalarchives.gov.uk/20101124142120/http:/www.dft.gov.uk/pgr/sustainable/travelplans/ptp/practictionersguide.pdf [Accessed September 2014].
DEPARTMENT FOR TRANSPORT 2009. Transport Trends: 2009 Edition. *National Statistics.* Available: http://webarchive.nationalarchives.gov.uk/20100406130654/http:/www.dft.gov.uk/adobepdf/162469/221412/190425/220778/trends2009.pdf [Accessed May 2016].
DEPARTMENT FOR TRANSPORT 2015 https://www.gov.uk/government/publications/2010-to-2015-government-policy-local-transport/2010-to-2015-government-policy-local-transport.
DG MOVE 2012. Study on Urban Freight Transport. Brussels: European Commission, Directorate-General for Mobility and Transport. Available: http://ec.europa.eu/transport/themes/urban/studies/doc/2012-04-urban-freight-transport.pdf [Accessed September 2014].
DG TREN 2010. Study on Urban Access Restrictions. Available: http://ec.europa.eu/transport/themes/urban/studies/doc/2010_12_ars_final_report.pdf.
DHONDT, S., KOCHAN, B., BECKX, C., LEFEBVRE, W., PIRDAVANI, A., DEGRAEUWE, B., BELLEMANS, T., INT PANIS, L., MACHARIS, C. & PUTMAN, K. 2013. Integrated health impact assessment of travel behaviour: model exploration and application to a fuel price increase. *Environ Int,* 51**,** 45-58.
DHONDT, S., KOCHAN, B., BECKX, C., LEFEBVRE, W., PIRDAVANI, A., DEGRAEUWE, B., BELLMANS, T., PANIS, L. I., MACHARIS, C. & PUTMAN, K. 2013. Integrated health impact assessment of travel behaviour: Model exploration and application to a fuel price increase. *Environment International.*51**,** 45-58.
DIEPLINGER, M. & FÜRST, E. 2014. The acceptability of road pricing: Evidence from two studies in Vienna and four other European cities. *Transport Policy.*36**,** 10-18.
DIONISIO, K. L., ARKU, R. E., HUGHES, A. F., VALLARINO, J., CARMICHAEL, H., SPENGLER, J. D., AGYEI-MENSAH, S. & EZZATI, M. 2010. Air pollution in Accra neighborhoods: spatial, socioeconomic, and temporal patterns. *Environ Sci Technol,* 44**,** 2270-6.
DOUCETTE, R. T. & MCCULLOCH, M. D. 2011. Modeling the prospects of plug-in hybrid electric vehicles to reduce CO2 emissions. *Applied Energy,* 88**,** 2315-2323.
DOUGHERTY, C. 2009. Driving Out of Germany, to Pollute Another Day. August 7, 2009. Available: http://www.nytimes.com/2009/08/08/world/europe/08germany.html?hpw&_r=0 [Accessed May 2016].
DRUMMOND, M. B. 2014. Obstructive airway disease in urban populations. *Curr Opin Pulm Med,* 20**,** 180-5.
ECKELMAN, M. J., CIACCI, L., KAVLAK, G., NUSS, P., RECK, B. K. & GRAEDEL, T. E. 2014. Life cycle carbon benefits of aerospace alloy recycling. *Journal of Cleaner Production,* 80**,** 38-45.
EICHLER, M. & DAGANZO, C. F. 2006. Bus lanes with intermittent priority: Strategy formulae and an evaluation. *Transportation Research Part B: Methodological.*40**,** 731-744.
ELGOWAINY, A., ROUSSEAU, A., WANG, M., RUTH, M., ANDRESS, D., WARD, J., JOSECK, F., NGUYEN, T. & DAS, S. 2013. Cost of ownership and well-to-wheels carbon emissions/oil use of alternative fuels and advanced light-duty vehicle technologies. *Energy for Sustainable Development,* 17**,** 626-641.
ELIASSON, J. 2009. A cost–benefit analysis of the Stockholm congestion charging system. *Transportation Research Part A: Policy and Practice.*43**,** 468-480.
ELLISON, R. B., GREAVES, S. P. & HENSHER, D. A. 2013. Five years of London's low emission zone: Effects on vehicle fleet composition and air quality. *Transportation Research Part D: Transport and Environment.*23**,** 25-33.
ENERGY SAVING TRUST EST 2013. Smarter Driving. Available: http://www.energysavingtrust.org.uk/Organisations/Transport/Products-and-services/Smarter-Driving [Accessed 18 December 2013].
EPUK/IAQM 2015. Guidance on land-use planning and development control: Planning for air quality. Available: www.iaqm.co.uk/text/guidance/air-quality-planning-guidance.pdf [Accessed May 2016].
ERNST, C.-S., HACKBARTH, A., MADLENER, R., LUNZ, B., UWE SAUER, D. & ECKSTEIN, L. 2011. Battery sizing for

serial plug-in hybrid electric vehicles: A model-based economic analysis for Germany. *Energy Policy,* 39**,** 5871-5882.

EST 2014. Driving Tax Savings. *http://www.energysavingtrust.org.uk/businesses/sites/default/files/Driving%2Btax%2Bsavings.pdf [Accessed 05/11/2014]*

EUROPEAN PARLIAMENT. 2010. *The Promotion of Cycling* [Online]. Available: https://ecf.com/sites/ecf.com/files/European-Parliament-2010_Promotion-of-Cycling.pdf.

EUROPEAN COMMISSION 2014 Catalogue of air quality measures. https://luft.umweltbundesamt.at/measures/ [*Accessed 2014]*

FARIA, R., MARQUES, P., MOURA, P., FREIRE, F., DELGADO, J. & DE ALMEIDA, A. T. 2013. Impact of the electricity mix and use profile in the life-cycle assessment of electric vehicles. *Renewable and Sustainable Energy Reviews,* 24**,** 271-287.

FARIA, R., MOURA, P., DELGADO, J. & DE ALMEIDA, A. T. 2012. A sustainability assessment of electric vehicles as a personal mobility system. *Energy Conversion and Management,* 61**,** 19-30.

FENG, X., GE, Y., MA, C., TAN, J., YU, L., LI, J. & WANG, X. 2014. Experimental study on the nitrogen dioxide and particulate matter emissions from diesel engine retrofitted with particulate oxidation catalyst. *Science of The Total Environment.*472**,** 56-62.

FERRARI, P. 2005. Road pricing and users' surplus. *Transport Policy.*12**,** 477-487.

FERRARI, P. 2010. Willingness to spend and road pricing rates. *Transport Policy.*17**,** 160-172.

FERREIRA, F., GOMES. P., TENTE, H., CARVALLIO, A.C., PEREIRA, P. MONJARDINO.J. 2015. Air quality improvements following implementation of Lisbon's low emission zone. *Atmospheric Environment,* 122, 373-38.

FINKLEMAN, J., CASELLO, J. & FU, L. 2011. Empirical evidence from the Greater Toronto Area on the acceptability and impacts of HOT lanes. *Transport Policy.*18**,** 814-824.

FISHMAN, E., WASHINGTON, S. & HAWORTH, N. 2014. Bike share's impact on car use: Evidence from the United States, Great Britain, and Australia. *Transportation Research Part D: Transport and Environment.*31**,** 13-20.

FISHMAN, E., WASHINGTON, S. & HAWORTH, N. 2014. Bike share's impact on car use: Evidence from the United States, Great Britain, and Australia. . *Transportation Research Part D* 31**,** 13-20.

FOLEY, A., TYTHER, B., CALNAN, P. & Ó GALLACHÓIR, B. 2013. Impacts of Electric Vehicle charging under electricity market operations. *Applied Energy,* 101**,** 93-102.

FONTES, T., FERNANDES, P., RODRIGUES, H., BANDEIRA, J. M., PEREIRA, S. R., KHATTAK, A. J. & COELHO, M. C. 2014. Are HOV/eco-lanes a sustainable option to reducing emissions in a medium-sized European city? *Transportation Research Part A: Policy and Practice,* 63**,** 93-106.

FONTES, T. & PEREIRA, S. R. 2014. Impact assessment of road fleet transitions on emissions: The case study of a medium European size country. *Energy Policy,* 72**,** 175-185.

FOSGERAU, M. & DE PALMA, A. 2013. The dynamics of urban traffic congestion and the price of parking. *Journal of Public Economics,* 105**,** 106-115.

FOSGERAU, M. & JENSEN, T. C. 2013. A green reform is not always green. *Transportation Research Part C: Emerging Technologies.*30**,** 210-220.

FRADE, I. & RIBEIRO, A. 2014. Bicycle Sharing Systems Demand. *Procedia - Social and Behavioral Sciences,* 111**,** 518-527.

FRANCKE, A. & KANIOK, D. 2013. Responses to differentiated road pricing schemes. *Transportation Research Part A: Policy and Practice.*48**,** 25-30.

FRANK, L., KAVAGE, S. & LITMAN, T. 2006. Promoting Public Health Through Smart Growth: Building Healthier Communities Through Transportation And Land Use Policies. Available: www.vtpi.org/sgbc_health.pdf [Accessed 13 December 2013].

FREIGHT TRANSPORT ASSOCIATION 2014. Gas rec newsletter http://gasrec.co.uk/gasrec-newsletter-edition-2-august-2014/ [Accessed 2014]

FRIGO, S., SEGGIANI, M., PUCCINI, M. & VITOLO, S. 2014. Liquid fuel production from waste tyre pyrolysis and its utilisation in a Diesel engine. *Fuel,* 116**,** 399-408.

FU, M. & ANDREW KELLY, J. 2012. Carbon related taxation policies for road transport: Efficacy of ownership and usage taxes, and the role of public transport and motorist cost perception on policy outcomes. *Transport Policy.*22**,** 57-69.

FUGLESTVEDT, J., BERNTSEN, T., MYHRE, G., RYPDAL, K. & SKEIE, R. B. 2008. Climate forcing from the transport sectors. *Proc Natl Acad Sci U S A,* 105**,** 454-8.

FUJISAKI, K. 2014. An empirical analysis of effects of gasoline price change on transportation behavior in Japan, with consideration of regional differences. *Socio-Economic Planning Sciences.*48**,** 220-233.

FURUKAWA, J., TAKADA, T., MONMA, D. & LAM, L. T. 2010. Further demonstration of the VRLA-type UltraBattery under medium-HEV duty and development of the flooded-type UltraBattery for micro-HEV applications. *Journal of Power Sources,* 195**,** 1241-1245.

FYHRI, A. & KLAEBOE, R. 2009. Road traffic noise, sensitivity, annoyance and self-reported health--a structural equation model exercise. *Environ Int.* 2008/10/01 ed.35**,** 91-7.

GARCÍA-PALOMARES, J. C., GUTIÉRREZ, J. & LATORRE, M. 2012. Optimizing the location of stations in bike-sharing programs: A GIS approach. *Applied Geography.*35**,** 235-246.

GEROLIMINIS, N., ZHENG, N. & AMPOUNTOLAS, K. 2014. A three-dimensional macroscopic fundamental diagram for mixed bi-modal urban networks. *Transportation Research Part C: Emerging Technologies,* 42**,** 168-181.

GERSSEN-GONDELACH, S. J. & FAAIJ, A. P. C. 2012. Performance of batteries for electric vehicles on short and longer term. *Journal of Power Sources,* 212**,** 111-129.

GIULIANO, G. & LINDER, A. 2013. Motivations for self-regulation: The clean air action plan. *Energy Policy,* 59**,** 513-522.

GLA TRANSPORT COMMITTEE 2010. Pedal power: the cycle hire scheme and cycle superhighways. London. Available: http://www.london.gov.uk/sites/default/files/FINAL%20REPORT.pdf.

GOH, K., CURRIE, G., SARVI, M. & LOGAN, D. 2014. Factors affecting the probability of bus drivers being at-fault in bus-involved accidents. *Accident Analysis & Prevention,* 66**,** 20-26.

GOLD, D. R. & WRIGHT, R. 2005. Population disparities in asthma. *Annu Rev Public Health,* 26**,** 89-113.

GOODWIN, P. & LYONS, G. 2010. Public attitudes to transport: interpreting the evidence, in Transportation. *Planning and Technology* 33**,** 3-17.

GORALSKI JR, C. T. & SCHNEIDER, W. F. 2002. Analysis of the thermodynamic feasibility of NOx decomposition catalysis to meet next generation vehicle NOx emissions standards. *Applied Catalysis B: Environmental.*37**,** 263-277.

GÖRANSSON, L., KARLSSON, S. & JOHNSSON, F. 2010. Integration of plug-in hybrid electric vehicles in a regional wind-thermal power system. *Energy Policy,* 38**,** 5482-5492.

GÖTEBORG'S STAD TRAFIKKONTORET 2006. Assessment of environmental zone in Göteborg. Available: http://www2.trafikkontoret.goteborg.se/resourcelibrary/Utv%C3%A4rdering%20MZ%2010%20%C3%A5r%20ENG.pdf.

GRAMSCH, E., ORMENO, I., PALMA, G., CERECEDA-BALIC, F. & OYOLA, P. 2004. Use of the light absorption coefficient to monitor elemental carbon and PM2.5--example of Santiago de Chile. *J Air Waste Manag Assoc,* 54**,** 799-808.

GRAY, D., FARRINGTON, J., SHAW, J., MARTIN, S. & ROBERTS, D. 2001. Car dependence in rural Scotland: transport policy, devolution and the impact of the fuel duty escalator. *Journal of Rural Studies.*17**,** 113-125.

GREAVES, S., BACKMAN, H. & ELLISON, A. B. 2014. An empirical assessment of the feasibility of battery electric vehicles for day-to-day driving. *Transportation Research Part A: Policy and Practice.*66**,** 226-237.

GREENE, D. L. 2011. What is greener than a VMT tax? The case for an indexed energy user fee to finance us surface transportation. *Transportation Research Part D: Transport and Environment.*16**,** 451-458.

GREENE, D. L. 2011. What is greener than a VMT tax? The case for an indexed energy user fee to finance us surface transportation. *Transportation Research Part D: Transport and Environment,* 16**,** 451-458.

GTZ 2010. Recommended Reading and Links on Public Bicycle Schemes. *GTZ.* 13. Available: http://www.sutp.org/files/contents/documents/resources/F_Reading-Lists/GIZ_SUTP_RL-Public-Bike-Schemes_EN.pdf [Accessed May 2016].

GUBINS, S. & VERHOEF, E. T. 2014. Dynamic bottleneck congestion and residential land use in the monocentric city. *Journal of Urban Economics,* 80**,** 51-61.

GULER, S. I. & MENENDEZ, M. 2014. Analytical formulation and empirical evaluation of pre-signals for bus priority. *Transportation Research Part B: Methodological.*64**,** 41-53.

GUO, J., GE, Y., HAO, L., TAN, J., LI, J. & FENG, X. 2014. On-road measurement of regulated pollutants from diesel and CNG buses with urea selective catalytic reduction systems. *Atmospheric Environment,* 99**,** 1-9.

HANSEN, A. C. 2010. Will hydrogen be competitive in Europe without tax favours? *Energy Policy.*38**,** 5346-5358.

HAO, H., WANG, H. & OUYANG, M. 2011. Fuel conservation and GHG (Greenhouse gas) emissions mitigation scenarios for China's passenger vehicle fleet. *Energy,* 36**,** 6520-6528.

HAUCK, P., JENTYS, A. & LERCHER, J. A. 2007. Surface chemistry and kinetics of the hydrolysis of isocyanic acid on anatase. *Applied Catalysis B: Environmental,* 70**,** 91-99.

HEEB, N. V., ZIMMERLI, Y., CZERWINSKI, J., SCHMID, P., ZENNEGG, M., HAAG, R., SEILER, C., WICHSER, A., ULRICH, A., HONEGGER, P., ZEYER, K., EMMENEGGER, L., MOSIMANN, T., KASPER, M. & MAYER, A. 2011. Reactive nitrogen compounds (RNCs) in exhaust of advanced PM–NOx abatement technologies for future diesel applications. *Atmospheric Environment,* 45**,** 3203-3209.

HEKKERT, M. P., HENDRIKS, F. H. J. F., FAAIJ, A. P. C. & NEELIS, M. L. 2005. Natural gas as an alternative to crude oil in automotive fuel chains well-to-wheel analysis and transition strategy development. *Energy Policy,* 33**,** 579-594.

HICKSON, A. 2006. Motor vehicle insurance rating with pseudo emissions coverage. *Ecological Economics.*58**,** 146-159.

HITCHCOCK, G., CONLAN, B., KAY, D., BRANNIGAN, C. & NEWMAN, D. 2014. Air Quality and Road Transport Impacts and solutions. *RAC Foundation*. 139.

HMRC 2006. Report on the Evaluation of the Company Car Tax Reform:stage2, Her Majesty's Revenue and Customs, 22 March 2006. Available: http://webarchive.nationalarchives.gov.uk/20091222074811/http:/www.hmrc.gov.uk/cars/stage-2-evaluation.pdf [Accessed May 2016].

HOLGUÍN-VERAS, J. 2008. Necessary conditions for off-hour deliveries and the effectiveness of urban freight road pricing and alternative financial policies in competitive markets. *Transportation Research Part A: Policy and Practice*.42**,** 392-413.

HOLGUÍN-VERAS, J. 2010. The truth, the myths and the possible in freight road pricing in congested urban areas. *Procedia - Social and Behavioral Sciences*.2**,** 6366-6377.

HOLGUÍN-VERAS, J. & CETIN, M. 2009. Optimal tolls for multi-class traffic: Analytical formulations and policy implications. *Transportation Research Part A: Policy and Practice*.43**,** 445-467.

HOLMAN, C., HARRISON, R. QUEROL, X 2015. Review of the efficacy of low emission zones to improve urban air quality in European cities. *Atmospheric Environment* 111,161-169.

HOU, Q., AN, X. Q., WANG, Y. & GUO, J. P. 2010. An evaluation of resident exposure to respirable particulate matter and health economic loss in Beijing during Beijing 2008 Olympic Games. *Sci Total Environ,* 408**,** 4026-32.

HOUEL, V., MILLINGTON, P., RAJARAM, R. & TSOLAKIS, A. 2007. Promoting functions of H2 in diesel-SCR over silver catalysts. *Applied Catalysis B: Environmental,* 77**,** 29-34.

HUO, H. & WANG, M. 2012. Modeling future vehicle sales and stock in China. *Energy Policy*.43**,** 17-29.

HUTCHISON, K. D., SMITH, S. & FARUQUI, S. 2004. The use of MODIS data and aerosol products for air quality prediction. *Atmospheric Environment,* 38**,** 5057-5070.

HWANG, J.-J. 2013. Sustainability study of hydrogen pathways for fuel cell vehicle applications. *Renewable and Sustainable Energy Reviews,* 19**,** 220-229.

HWANG, J.-J., KUO, J.-K., WU, W., CHANG, W.-R., LIN, C.-H. & WANG, S.-E. 2013. Lifecycle performance assessment of fuel cell/battery electric vehicles. *International Journal of Hydrogen Energy,* 38**,** 3433-3446.

ICCT 2014. Assessment of PEMS Datasets from Modern Diesel Passenger Cars. . *International Transport and Air Pollution Conference, Graz, Austria, 18-19 September, 2014*. Available: http://www.theicct.org/sites/default/files/publications/ICCT_PEMS-study_diesel-cars_20141010.pdf [Accessed May 2016].

IHS GLOBAL INSIGHT 2010. Assessment of the Effectiveness of Scrapping Schemes for Vehicles. Economic, Environmental and Safety Impacts.

INES, F. & RIBEIRO, A. 2014 Bicycle sharing systems demand. Procedia-Social and Behavioral Sciences, 111, 518-527.

INSTITUTE FOR TRANSPORTATION AND DEVELOPMENT POLICY (ITDP) 2013. The Bike-share Planning Guide. Available: http://www.itdp.org/documents/ITDP_Bike_Share_Planning_Guide.pdf [Accessed 18 December 2013].

INT PANIS, L., DE NOCKER, L., CORNELIS, E. & TORFS, R. 2004. An uncertainty analysis of air pollution externalities from road transport in Belgium in 2010. *Sci Total Environ*. 2004/10/27 ed.334-335**,** 287-98.

INT PANIS, L., DE NOCKER, L., CORNELIS, E. & TORFS, R. 2004. An uncertainty analysis of air pollution externalities from road transport in Belgium in 2010. *Sci Total Environ,* 334-335**,** 287-98.

INTURRI, G. & IGNACCOLO, M. 2011. Modelling the impact of alternative pricing policies on an urban multimodal traffic corridor. *Transport Policy,* 18**,** 777-785.

INVERNIZZIA, G., RUPRECHTA, A., MAZZAB, R., DE MARCOB, C., MOČNIKC, G., SIOUTASD, C. & WESTERDAHLE, D. 2011. Measurement of black carbon concentration as an indicator of air quality benefits of traffic restriction policies within the ecopass zone in Milan, Italy. *Atmospheric Environment*.45.

ISON, S. 2000. Local authority and academic attitudes to urban road pricing: a UK perspective. *Transport Policy*.7**,** 269-277.

ITDP 2011. Europe's Parking U-Turn: From Accommodation to Regulation. Institute for Transportation and Development policy. Available: https://www.itdp.org/wp-content/uploads/2014/07/Europes_Parking_U-Turn_ITDP.pdf.

ITF 2010. REDUCING TRANSPORT GHG EMISSIONS Opportunities and Costs. 24.

I-TRAQ 2013. Integrating traffic control and air quality. Available: http://iap.esa.int/projects/transport/itraq [Accessed 3 July 2013].

JANSSON, J. O. 2010. Road pricing and parking policy. *Research in Transportation Economics*.29**,** 346-353.

JÄPPINEN, S., TOIVONEN, T. & SALONEN, M. 2013. Modelling the potential effect of shared bicycles on public transport travel times in Greater Helsinki: An open data approach. *Applied Geography*.43**,** 13-24.

JARAMILLO, P., SAMARAS, C., WAKELEY, H. & MEISTERLING, K. 2009. Greenhouse gas implications of using coal for transportation: Life cycle assessment of coal-to-liquids, plug-in hybrids, and hydrogen pathways. *Energy Policy,* 37**,** 2689-2695.

JAZCILEVICH, A. D., REYNOSO, A. G., GRUTTER, M., DELGADO, J., AYALA, U. D., LASTRA, M. S., ZUK, M., OROPEZA, R. G., LENTS, J. & DAVIS, N. 2011. An evaluation of the hybrid car technology for the Mexico Mega City. *Journal of Power Sources,* 196**,** 5704-5718.

JENSEN, S. S., KETZEL, M., BRANDT, J. & WINTHER, M. 2012. No. 25: Assessment of air quality in low emission zones in Copenhagen. *Danish Centre For Environment And Energy (DCE).*1.

JENSEN, S. S., KETZEL, M., NØJGAARD, J. K. & BECKER, T. 2011a. No. 830: Effects on air quality of the low emission zones in Copenhagen, Frederiksberg, Aarhus, Odense and Aalborg. *Danish Centre For Environment And Energy (DCE).*830.

JENSEN, S. S., KETZEL, M., NØJGAARD, J. K. & BECKER, T. 2011b. What are the Impacts on Air Quality of Low Emission Zones in Denmark? *Proceedings from the Annual Transport Conference, Aalborg University.*

JIMENEZ, G. & FLORES, J. M. 2015. Reducing the CO2 emissions and the energy dependence of a large city area with zero-emission vehicles and nuclear energy. *Progress in Nuclear Energy,* 78**,** 396-403.

JIMENEZ-ESPADAFOR, F. J., MARÍN, J. J. R., BECERRA VILLANUEVA, J. A., GARCÍA, M. T., TRUJILLO, E. C. & OJEDA, F. J. F. 2011. Infantry mobility hybrid electric vehicle performance analysis and design. *Applied Energy,* 88**,** 2641-2652.

JOELSSON, J. M. & GUSTAVSSON, L. 2010. Reduction of CO2 emission and oil dependency with biomass-based polygeneration. *Biomass and Bioenergy,* 34**,** 967-984.

JOHANSSON, C., BURMAN, L. & FORSBERG, B. 2009. The effects of congestions tax on air quality and health. *Atmospheric Environment.*43**,** 4843-4854.

JOHNSON, M., HUDGENS, E., WILLIAMS, R., ANDREWS, G., NEAS, L., GALLAGHER, J. & OZKAYNAK, H. 2009. A participant-based approach to indoor/outdoor air monitoring in community health studies. *J Expo Sci Environ Epidemiol,* 19**,** 492-501.

JOHNSON, T. V. 2006. Diesel Emission Control in Review. *SAE International - SAE Technical Paper Series.*

JONES, A. M., HARRISON, R. M., BARRATT, B. & FULLER, G. 2012. A large reduction in airborne particle number concentrations at the time of the introduction of "sulphur free" diesel and the London Low Emission Zone. *Atmospheric Environment.*50**,** 129-138.

JONES, G. & PARKER, T. 2007. Stage 1 Report: Feasibility Study on a Low Emission Zone for Oxford. AEA technology report for Oxford City Council. Available: http://repairshandbook.oxford.gov.uk/Direct/78443Item5part2.pdf.

JUNK, J., HELBIG, A. & KREIN, A. 2004. Screening and scenarios of traffic emissions at Trier, Germany. *Environ Sci Pollut Res Int,* 11**,** 297-301.

KAGAWA, S., HUBACEK, K., NANSAI, K., KATAOKA, M., MANAGI, S., SUH, S. & KUDOH, Y. 2013. Better cars or older cars?: Assessing CO2 emission reduction potential of passenger vehicle replacement programs. *Global Environmental Change.*23**,** 1807-1818.

KALLBEKKEN, S., GARCIA, J. H. & KORNELIUSSEN, K. 2013. Determinants of public support for transport taxes. *Transportation Research Part A: Policy and Practice.*58**,** 67-78.

KALLBEKKEN, S., GARCIA, J. H. & KORNELIUSSEN, K. 2013. Determinants of public support for transport taxes. *Transportation Research Part A: Policy and Practice.*58**,** 67-78.

KARPLUS, V. J., PALTSEV, S., BABIKER, M. & REILLY, J. M. 2013. Should a vehicle fuel economy standard be combined with an economy-wide greenhouse gas emissions constraint? Implications for energy and climate policy in the United States. *Energy Economics.*36**,** 322-333.

KARPLUS, V. J., PALTSEV, S. & REILLY, J. M. 2010. Prospects for plug-in hybrid electric vehicles in the United States and Japan: A general equilibrium analysis. *Transportation Research Part A: Policy and Practice,* 44**,** 620-641.

KATRAŠNIK, T. 2013. Impact of vehicle propulsion electrification on Well-to-Wheel CO2 emissions of a medium duty truck. *Applied Energy,* 108**,** 236-247.

KATSOYIANNIS, A., BIRGUL, A., RATOLA, N., CINCINELLI, A., SWEETMAN, A. J. & JONES, K. C. 2012. Can car air filters be useful as a sampling medium for air pollution monitoring purposes? *Environ Int,* 48**,** 65-70.

KELLY, F., ANDERSON, H. R., ARMSTRONG, B., ATKINSON, R., BARRATT, B., BEEVERS, S., DERWENT, D., GREEN, D., MUDWAY, I., WILKINSON, P. & COMMITTEE, H. E. I. H. R. 2011a. The impact of the congestion charging scheme on air quality in London. Part 1. Emissions modeling and analysis of air pollution measurements. *Res Rep Health Eff Inst.* 5-71.

KELLY, F., ARMSTRONG, B., ATKINSON, R., ANDERSON, H. R., BARRATT, B., BEEVERS, S., COOK, D., GREEN, D., DERWENT, D., MUDWAY, I., WILKINSON, P. & COMMITTEE, H. E. I. H. R. 2011b. The London low emission zone baseline study. *Res Rep Health Eff Inst.* 3-79.

KEUKEN, M. P., JONKERS, S., ZANDVELD, P., VOOGT, M. & ELSHOUT VAN DEN, S. 2012. Elemental carbon as an indicator for evaluating the impact of traffic measures on air quality and health. *Atmospheric*

*Environment.*61**,** 1-8.
KIM, H. C., ROSS, M. H. & KEOLEIAN, G. A. 2004. Optimal fleet conversion policy from a life cycle perspective. *Transportation Research Part D: Transport and Environment.*9**,** 229-249.
KOEHLER, L. A. & KRAUS JR, W. 2010. Simultaneous control of traffic lights and bus departure for priority operation. *Transportation Research Part C: Emerging Technologies,* 18**,** 288-298.
KOLLER, D. & MIELCK, A. 2009. Regional and social differences concerning overweight, participation in health check-ups and vaccination. Analysis of data from a whole birth cohort of 6-year old children in a prosperous German city. *BMC Public Health,* 9**,** 43.
KRUPA, J. S., RIZZO, D. M., EPPSTEIN, M. J., BRAD LANUTE, D., GAALEMA, D. E., LAKKARAJU, K. & WARRENDER, C. E. 2014. Analysis of a consumer survey on plug-in hybrid electric vehicles. *Transportation Research Part A: Policy and Practice,* 64**,** 14-31.
KUNZLI, N. 2000. Ministers of Health, Environment, Traffic, Economy: you need to have lunch together! *Soz Praventivmed,* 45**,** 237-8.
KUSAKA, J. E. A. 2005. A basic study on a urea-selective catalytic reduction system for a medium-duty diesel engine. *International Journal of Engine Research.*6**,** 11-19.
LANE, B. 2009. Is the car scrappage scheme helping the environment? The Guardian. Available: http://www.theguardian.com/environment/ethicallivingblog/2009/aug/21/car-scrappage-carbon-emissions.
LANE, B. 2016. Are LPG and natural gas cars better for the environment? . Available: www.nextgreencar.com/lpg-cng.php [Accessed May 2016].
LAWRENCE, C. D. 2003. 9 - The Production of Low-Energy Cements. *In:* HEWLETT, P. C. (ed.) *Lea's Chemistry of Cement and Concrete (Fourth Edition).* Oxford: Butterworth-Heinemann.
LEBEN, J. & HOČEVAR, S. 2012. Correlation between national development indicators and the implementation of a hydrogen economy in Slovenia. *International Journal of Hydrogen Energy,* 37**,** 5468-5480.
LEE, J.-Y., AN, S., CHA, K. & HUR, T. 2010. Life cycle environmental and economic analyses of a hydrogen station with wind energy. *International Journal of Hydrogen Energy.*35**,** 2213-2225.
LEE, J.-Y., AN, S., CHA, K. & HUR, T. 2010. Life cycle environmental and economic analyses of a hydrogen station with wind energy. *International Journal of Hydrogen Energy,* 35**,** 2213-2225.
LEE, J.-Y., YU, M.-S., CHA, K.-H., LEE, S.-Y., LIM, T. W. & HUR, T. 2009. A study on the environmental aspects of hydrogen pathways in Korea. *International Journal of Hydrogen Energy.*34**,** 8455-8467.
LEHEYDA, N. & VERBOVEN, F. 2013. Scrapping Subsidies during the Financial Crisis -Evidence from the Europe *Ku Leuven Centre for economic studies DISCUSSION PAPER SERIES PS13.13 AUGUST 2013*.
LEIGH, J. P. & GERAGHTY, E. M. 2008. High gasoline prices and mortality from motor vehicle crashes and air pollution. *J Occup Environ Med,* 50**,** 249-54.
LEINERT, S., DALY, H., HYDE, B. & O GALLACHOIR, B. P. 2013. Co-benefits? Not always: Quantifying the negative effect of a CO2-reducing car taxation policy on NOx emissions. *Energy Policy,* 63**,** 1151-1159.
LENSKI, S. M., KEOLEIAN, G. A. & MOORE, M. R. 2013. An assessment of two environmental and economic benefits of 'Cash for Clunkers'. *Ecological Economics.*96**,** 173-180.
LEVY, J. I., BAXTER, L. K. & CLOUGHERTY, J. E. 2006. The air quality impacts of road closures associated with the 2004 Democratic National Convention in Boston. *Environ Health,* 5**,** 16.
LEWIS, A. M., KELLY, J. C. & KEOLEIAN, G. A. 2014. Vehicle lightweighting vs. electrification: Life cycle energy and GHG emissions results for diverse powertrain vehicles. *Applied Energy.*126**,** 13-20.
LI, H., GRAHAM, D. J. & MAJUMDAR, A. 2012. The effects of congestion charging on road traffic casualties: A causal analysis using difference-in-difference estimation. *Accident Analysis & Prevention.*49**,** 366-377.
LI, X. & OGDEN, J. M. 2011. Understanding the design and economics of distributed tri-generation systems for home and neighborhood refueling—Part I: Single family residence case studies. *Journal of Power Sources.*196**,** 2098-2108.
LINDNER, G., SALA-MOORE, S. ET AL. 2008. Proposed regulation for in-use on-road vehicles. Available: http://www.arb.ca.gov/regact/2008/truckbus08/tbisor.pdf
LINDSAY, G., MACMILLAN, A. & WOODWARD, A. 2011. Moving urban trips from cars to bicycles: impact on health and emissions. *Aust N Z J Public Health,* 35**,** 54-60.
LIPFERT, F. W., BATY, J. D., MILLER, J. P. & WYZGA, R. E. 2006. PM2.5 constituents and related air quality variables as predictors of survival in a cohort of U.S. military veterans. *Inhal Toxicol,* 18**,** 645-57.
LIU, C. & ZHENG, Z. 2013. Public Acceptance towards Congestion Charge: A Case Study of Brisbane. *Procedia - Social and Behavioral Sciences.*96**,** 2811-2822.
LIU, H., ZHANG, J. & CHENG, D. 2008. Analytical Approach to Evaluating Transit Signal Priority. *Journal of Transportation Systems Engineering and Information Technology.*8**,** 48-57.
LIU, Z. G., BERG, D.R. ET AL. 2008. Comparative analysis on the effects of diesel particulate filter and selective catalytic reduction systems on a wide spectrum of chemical species emissions. *Environ. Sci. Technol.*42**,**

6080-6085.
LONDON, S. J. & ROMIEU, I. 2000. Health costs due to outdoor air pollution by traffic. *Lancet,* 356, 782-3.
LÓPEZ, J. M., JIMÉNEZ, F., APARICIO, F. & FLORES, N. 2009. On-road emissions from urban buses with SCR + Urea and EGR + DPF systems using diesel and biodiesel. *Transportation Research Part D: Transport and Environment.*14, 1-5.
LORENZ STÖR (IÖW), S. M. I. A. D. F. R. I. 2013. Bike-Sharing in European Urban Mobility. *Responder*. Available: http://www.mobile2020.eu/fileadmin/files_sk/downloads/RESPONDER_KU_bike-sharing.pdf [Accessed May 2016].
LUCAS, A., NETO, R. C. & SILVA, C. A. 2012. Impact of energy supply infrastructure in life cycle analysis of hydrogen and electric systems applied to the Portuguese transportation sector. *International Journal of Hydrogen Energy.*37, 10973-10985.
LUO, J.-Y., OH, H., HENRY, C. & EPLING, W. 2012. Effect of C3H6 on selective catalytic reduction of NOx by NH3 over a Cu/zeolite catalyst: A mechanistic study. *Applied Catalysis B: Environmental.*123–124, 296-305.
LUTZ, M. 2009. The low emission zone in Berlin – results of a first impact assessment. Available: http://www.stadtentwicklung.berlin.de/umwelt/luftqualitaet/de/luftreinhalteplan/download/paper_lez_berlin_en.pdf [Accessed 7 July 2012].
MA, L., CHENG, Y., CAVATAIO, G., MCCABE, R. W., FU, L. & LI, J. 2014. In situ DRIFTS and temperature-programmed technology study on NH3-SCR of NOx over Cu-SSZ-13 and Cu-SAPO-34 catalysts. *Applied Catalysis B: Environmental.*156–157, 428-437.
MA, W., HEAD, K. L. & FENG, Y. 2014. Integrated optimization of transit priority operation at isolated intersections: A person-capacity-based approach. *Transportation Research Part C: Emerging Technologies.*40, 49-62.
MA, W. & YE, X. 2013. Optimal Offline Cycle Length Model Based on Online Bus Priority Demand. *Journal of Transportation Systems Engineering and Information Technology.*13, 124-129.
MACPHERSON, A. & PRITCHARD, D. 2003. The international decentralisation of US commercial aircraft production: implications for US employment and trade. *Futures,* 35, 221-238.
MAERIVOET, S., DAEMS, F., MAERTENS, F., RENCKENS, K., VAN HOUTTE, P. & BUELENS, L. 2012. A Field Trial on Smart Mobility. *Procedia - Social and Behavioral Sciences.*54, 926-935.
MALINA, C. SCHEFFLER, F. 2015. The impact of low emission zones on particulate matter concentration and public health. Transportation Research, Part A 77, 372-385.
MAMAT, A. M. I., ROMAGNOLI, A. & MARTINEZ-BOTAS, R. F. 2014. Characterisation of a low pressure turbine for turbocompounding applications in a heavily downsized mild-hybrid gasoline engine. *Energy,* 64, 3-16.
MAO, X., YANG, S., LIU, Q., TU, J. & JACCARD, M. 2012. Achieving CO2 emission reduction and the co-benefits of local air pollution abatement in the transportation sector of China. *Environmental Science & Policy.*21, 1-13.
MARIN, E. 2003. Demand forecast, congestion charge and economic benefit of an automated highway network for the paris agglomeration. *Transport Policy.*10, 107-120.
MARSHALL, B. M., KELLY, J. C., LEE, T.-K., KEOLEIAN, G. A. & FILIPI, Z. 2013. Environmental assessment of plug-in hybrid electric vehicles using naturalistic drive cycles and vehicle travel patterns: A Michigan case study. *Energy Policy.*58, 358-370.
MARTIN, J. C. & POINT, P. 2012. Road project opportunity costs subject to a regional constraint on greenhouse gas emissions. *J Environ Manage,* 112, 292-303.
MARZOUK, M. & MADANY, M. 2012. Health effects associated with passenger vehicles: monetary values of air pollution. *Arch Environ Occup Health,* 67, 145-54.
MATSUMOTO, S. & SHINJOH, H. 2007. Dynamic behavior and characterization of automobile catalysts. *In:* GUY, B. M. (ed.) *Advances in Chemical Engineering.* Academic Press.
MAYERES, I. & PROOST, S. 2001. Should diesel cars in Europe be discouraged? *Regional Science and Urban Economics,* 31, 453-470.
MAYERES, I. & PROOST, S. 2013. The taxation of diesel cars in Belgium – revisited. *Energy Policy.*54, 33-41.
MCDONNELL, S. & ZELLNER, M. 2011. Exploring the effectiveness of bus rapid transit a prototype agent-based model of commuting behavior. *Transport Policy.*18, 825-835.
MCKINNON, A. C. 2006. Government plans for lorry road-user charging in the UK: a critique and an alternative. *Transport Policy.*13, 204-216.
MCMICHAEL, A. J. 2000. The urban environment and health in a world of increasing globalization: issues for developing countries. *Bull World Health Organ,* 78, 1117-26.
METZ, D. 2005. Journey quality as the focus of future transport policy. *Transport Policy.*12, 353-359.
MIDGLEY, P. 2009. The Role of Smart Bike-sharing Systems in Urban Mobility. *JOURNEYS.* 9.
MIDGLEY, P. 2011. Bicycle-sharing schemes: Enhancing Sustainable Mobility in Urban Areas. *Commission on Sustainable Development.* 26.
MILLET, C.-N., CHÉDOTAL, R. & DA COSTA, P. 2009. Synthetic gas bench study of a 4-way catalytic converter:

Catalytic oxidation, NOx storage/reduction and impact of soot loading and regeneration. *Applied Catalysis B: Environmental.*90**,** 339-346.

MILLO, F., ROLANDO, L., FUSO, R. & MALLAMO, F. 2014. Real CO2 emissions benefits and end user's operating costs of a plug-in Hybrid Electric Vehicle. *Applied Energy,* 114**,** 563-571.

MILLSTEIN, D. E., HARLET, R.A. 2010. Effects of Retrofitting Emission Control Systems on In-Use Heavy Diesel Vehicles. *Environ. Sci. Technol.*44,**,** 5042–5048.

MITCHELL, G. 2005. Forecasting environmental equity: Air quality responses to road user charging in Leeds, UK. *Journal of Environmental Management.*77**,** 212-226.

MITCHELL, G., NAMDEO, A. & MILNE, D. 2005. The air quality impact of cordon and distance based road user charging: An empirical study of Leeds, UK. *Atmospheric Environment.*39**,** 6231-6242.

MOHAN, V., SHAH, A., SHEFFIELD, J. W. & MARTIN, K. B. 2012. Design of a hydrogen community. *International Journal of Hydrogen Energy,* 37**,** 1214-1219.

MOLTER, A., LINDLEY, S., DE VOCHT, F., SIMPSON, A. & AGIUS, R. 2010. Modelling air pollution for epidemiologic research--Part I: A novel approach combining land use regression and air dispersion. *Sci Total Environ.* 2010/09/18 ed.408**,** 5862-9.

MONZON, A. & GUERRERO, M. J. 2004. Valuation of social and health effects of transport-related air pollution in Madrid (Spain). *Sci Total Environ.* 2004/10/27 ed.334-335**,** 427-34.

MOODIE, M., HABY, M., GALVIN, L., SWINBURN, B. & CARTER, R. 2009. Cost-effectiveness of active transport for primary school children - Walking School Bus program. *Int J Behav Nutr Phys Act.* 2009/09/15 ed.6**,** 63.

MOODLEY, K. G., SINGH, S. & GOVENDER, S. 2011. Passive monitoring of nitrogen dioxide in urban air: a case study of Durban metropolis, South Africa. *J Environ Manage,* 92**,** 2145-50.

MORE, P. M., NGUYEN, D. L., DONGARE, M. K., UMBARKAR, S. B., NUNS, N., GIRARDON, J. S., DUJARDIN, C., LANCELOT, C., MAMEDE, A. S. & GRANGER, P. 2015. Rational preparation of Ag and Au bimetallic catalysts for the hydrocarbon-SCR of NOx: Sequential deposition vs. coprecipitation method. *Applied Catalysis B: Environmental,* 162**,** 11-20.

MOWDAY, M. 2006. Equity and High-Occupancy Toll Lanes: Literature Review and Minnesotans' Perceptions About I-394 High-Occupancy Toll Lane. *Transportation Research Board 85th Annual Meeting.*

MURTONEN, T. & AAKKO-SAKSA, P. 2009. Alternative fuels with heavy-duty engines and vehicles. VTT Working Papers.

MUSTI, S. & KOCKELMAN, K. M. 2011. Evolution of the household vehicle fleet: Anticipating fleet composition, PHEV adoption and GHG emissions in Austin, Texas. *Transportation Research Part A: Policy and Practice,* 45**,** 707-720.

NAEI 2013. Fleet Weighted Road Transport Emission Factor 2011 *http://naei.defra.gov.uk/resources/RoadtransportEFs_NAEI11_v1.xls.*

NAESS-SCHMIDT, S. & WINIARCZYK, M. 2010. Company Car Taxation - Subsidies, Welfare and Environment, Copenhagen Economics, European Commission. Available: http://ec.europa.eu/taxation_customs/resources/documents/taxation/gen_info/economic_analysis/tax_papers/taxation_paper_22_en.pdf [Accessed May 2016].

NAMDEO, A. & STRINGER, C. 2008. Investigating the relationship between air pollution, health and social deprivation in Leeds, UK. *Environ Int.*34**,** 585-91.

NEJJARI, C., FILLEUL, L., ZIDOUNI, N., LAID, Y., ATEK, M., EL MEZIANE, A. & TESSIER, J. F. 2003. Air pollution: a new respiratory risk for cities in low-income countries. *Int J Tuberc Lung Dis,* 7**,** 223-31.

NESTLÉ 2009. Nestlé Waters converts lift truck fleet to Plug fuel cells. *Fuel Cells Bulletin.*2009**,** 2-3.

NORMAN, R., CAIRNCROSS, E., WITI, J. & BRADSHAW, D. 2007. Estimating the burden of disease attributable to urban outdoor air pollution in South Africa in 2000. *S Afr Med J,* 97**,** 782-90.

OFFER, G. J., HOWEY, D., CONTESTABILE, M., CLAGUE, R. & BRANDON, N. P. 2010. Comparative analysis of battery electric, hydrogen fuel cell and hybrid vehicles in a future sustainable road transport system. *Energy Policy,* 38**,** 24-29.

OLEV (THE OFFICE FOR LOW EMISSION VEHICLES) 2013. Driving the Future Today A strategy for ultra low emission vehicles in the UK. Available: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/239317/ultra-low-emission-vehicle-strategy.pdf [Accessed May 2016].

OU, X., ZHANG, X. & CHANG, S. 2010. Alternative fuel buses currently in use in China: Life-cycle fossil energy use, GHG emissions and policy recommendations. *Energy Policy,* 38**,** 406-418.

OU, X., ZHANG, X. & CHANG, S. 2010. Scenario analysis on alternative fuel/vehicle for China's future road transport: Life-cycle energy demand and GHG emissions. *Energy Policy,* 38**,** 3943-3956.

OWEN, B. 2005. Air quality impacts of speed-restriction zones for road traffic. *Science of The Total Environment.*340.

OXFORD CITY COUNCIL 2006. Local Air Quality Management: Central Oxford Air Quality Action Plan. Available:

https://www.oxford.gov.uk/downloads/file/542/air_quality_action_plan_2006 [Accessed May 2016].
PADGETT, P. E., MEADOWS, D., EUBANKS, E. & RYAN, W. E. 2008. Monitoring fugitive dust emissions from off-highway vehicles traveling on unpaved roads and trails using passive samplers. *Environ Monit Assess,* 144**,** 93-103.
PANTELIADIS, P., STRAK, M., HOEK, G., WEIJERS, E., VAN DER ZEE, S. & DIJKEMA, M. 2014. Implementation of a low emission zone and evaluation of effects on air quality by long-term monitoring. *Atmospheric Environment.*86**,** 113-119.
PARK, S. H., KIM, H. J. & LEE, C. S. 2010. Effects of dimethyl-ether (DME) spray behavior in the cylinder on the combustion and exhaust emissions characteristics of a high speed diesel engine. *Fuel Processing Technology,* 91**,** 504-513.
PARK, S. W. 2010. Optimization of combustion chamber geometry for stoichiometric diesel combustion using a micro genetic algorithm. *Fuel Processing Technology,* 91**,** 1742-1752.
PARKHURST, G. 2004. Air quality and the environmental transport policy discourse in Oxford. *Transportation Research Part D: Transport and Environment.*9**,** 419-436.
PARRY, I. W. H. 2008. How should heavy-duty trucks be taxed? *Journal of Urban Economics.*63**,** 651-668.
PASTER, M. D., AHLUWALIA, R. K., BERRY, G., ELGOWAINY, A., LASHER, S., MCKENNEY, K. & GARDINER, M. 2011. Hydrogen storage technology options for fuel cell vehicles: Well-to-wheel costs, energy efficiencies, and greenhouse gas emissions. *International Journal of Hydrogen Energy,* 36**,** 14534-14551.
PATANKAR, A. M. & TRIVEDI, P. L. 2011. Monetary burden of health impacts of air pollution in Mumbai, India: implications for public health policy. *Public Health,* 125**,** 157-64.
PENG, Z., WANG, T., HE, Y., YANG, X. & LU, L. 2013. Analysis of environmental and economic benefits of integrated Exhaust Energy Recovery (EER) for vehicles. *Applied Energy,* 105**,** 238-243.
PENN, J. P. & LINDLEY, C. A. 2003. Requirements and approach for a space tourism launch system. *Acta Astronautica,* 52**,** 49-75.
PERCOCO, M. 2014a. The effect of road pricing on traffic composition: Evidence from a natural experiment in Milan, Italy. *Transport Policy.*31**,** 55-60.
PERCOCO, M. 2014b. The impact of road pricing on housing prices: Preliminary evidence from Milan. *Transportation Research Part A: Policy and Practice.*67**,** 188-194.
PETERSDORFF, C., BOERMANS, T. & HARNISCH, J. 2006. Mitigation of CO2 emissions from the EU-15 building stock: beyond the EU Directive on the Energy Performance of Buildings. *Environ Sci Pollut Res Int,* 13**,** 350-8.
PHILLIPS, K. J., LONGHURST, P. J. & WAGLAND, S. T. 2014. Assessing the perception and reality of arguments against thermal waste treatment plants in terms of property prices. *Waste Manag,* 34**,** 219-25.
PONCE, N. A., HOGGATT, K. J., WILHELM, M. & RITZ, B. 2005. Preterm birth: the interaction of traffic-related air pollution with economic hardship in Los Angeles neighborhoods. *Am J Epidemiol,* 162**,** 140-8.
POSADA, F., WAGNER, D. V., BANSAL, G. & FERNANDEZ, R. 2015. Survey of best practices in reducing emissions through vehicle replacement programs. *The International Council on Clean Transportation, Washington.*
POWELL, N., LITTLE, M., REEVE, J., BAXTER, J., ROBINSON, S., HERBERT, A., MASON, A., STRANGE, P., CHARTERS, D., BENJAMIN, S. & ALEKSANDROVA, S. 2012. Auxiliary power units for range extended electric vehicles. *In:* GAYDON & WARWICKSHIRE (eds.) *Sustainable Vehicle Technologies.* Woodhead Publishing.
PROOST, S., DELHAYE, E., NIJS, W. & REGEMORTER, D. V. 2009. Will a radical transport pricing reform jeopardize the ambitious EU climate change objectives? *Energy Policy.*37**,** 3863-3871.
PRUD'HOMME, R. M. & BOCAREJO, J. P. 2005. The London congestion charge: A tentative economic appraisal. *Transport Policy.*12.
QADIR, R. M., ABBASZADE, G., SCHNELLE-KREIS, J., CHOW, J. C. & ZIMMERMANN, R. 2013. Concentrations and source contributions of particulate organic matter before and after implementation of a low emission zone in Munich, Germany. *Environmental Pollution.*175**,** 158-167.
QCEA 2010. Car scrapping - sense and nonsense of a popular scheme. Available: http://www.qcea.org/wp-content/uploads/2011/04/fs-carscrappage-en-2010.pdf [Accessed May 2016].
QIAN, Z., XIAO, F. & ZHANG, H. M. 2012. Managing morning commute traffic with parking. *Transportation Research Part B: Methodological,* 46**,** 894-916.
QIN, J., NI, L. L. & SHI, F. 2013. Mixed transportation network design under a sustainable development perspective. *ScientificWorldJournal.* 2013/03/12 ed.2013**,** 549735.
RAC FOUNDATION 2012a. Easy on the gas – the effectiveness of eco-driving. Available: http://www.racfoundation.org/assets/rac_foundation/content/downloadables/easy_on_the_gas-wengraf-aug2012.pdf [Accessed October 2012].
RAC FOUNDATION 2012b. Space Out – Perspectives on parking policy. Available: http://www.racfoundation.org/assets/rac_foundation/content/downloadables/spaced_out-bates_leibling-jul12.pdf [Accessed 8 January 2014].

RAMíREZ-SALGADO, J., MARíN-CRUZ, J. & ESTRADA-MARTíNEZ, A. 2003. The future of fuel cell in Mexico in the third millennium. *Journal of Power Sources,* 117**,** 102-109.
RAPAPORT, E. 2002. The Stockholm environmental zone, a method to curb air pollution from bus and truck traffic. *Transportation Research Part D: Transport and Environment.*7.
RAUX, C. & MARLOT, G. 2005. A system of tradable CO2 permits applied to fuel consumption by motorists. *Transport Policy.*12**,** 255-265.
REDELBACH, M., ÖZDEMIR, E. D. & FRIEDRICH, H. E. 2014. Optimizing battery sizes of plug-in hybrid and extended range electric vehicles for different user types. *Energy Policy,* 73**,** 158-168.
REINOSDOTTER, K., VIKLANDER, M. & MALMQVIST, P. A. 2003. Comparison of the effects of using local and central snow deposits: a case study in Lulea. *Water Sci Technol,* 48**,** 71-9.
RENTZIOU, A., GKRITZA, K. & SOULEYRETTE, R. R. 2012. VMT, energy consumption, and GHG emissions forecasting for passenger transportation. *Transportation Research Part A: Policy and Practice.*46**,** 487-500.
REXEIS, M. & HAUSBERGER, S. 2009. Trend of vehicle emission levels until 2020 – Prognosis based on current vehicle measurements and future emission legislation. *Atmospheric Environment.*43**,** 4689-4698.
RIBAU, J., SILVA, C., BRITO, F. P. & MARTINS, J. 2012. Analysis of four-stroke, Wankel, and microturbine based range extenders for electric vehicles. *Energy Conversion and Management,* 58**,** 120-133.
RIBAU, J. P., SILVA, C. M. & SOUSA, J. M. C. 2014. Efficiency, cost and life cycle CO2 optimization of fuel cell hybrid and plug-in hybrid urban buses. *Applied Energy,* 129**,** 320-335.
RICARDO-AEA 2013. Opportunities to overcome the barriers to uptake of low emission technologies for each commercial vehicle duty cycle. Available: http://www.smmt.co.uk/wp-content/uploads/sites/2/Report-identifying-3-key-opportunities-to-reduce-GHG-emissions-from-HGVs.pdf [Accessed 18 December 2013].
RICCI, O. 2012. Providing adequate economic incentives for bioenergies with CO2 capture and geological storage. *Energy Policy.*44**,** 362-373.
ROBERTS, I. 2009. The health co-benefits of climate change policies: doctors have a responsibility to future generations. *Clin Med,* 9**,** 212-3.
ROGAN, F., DENNEHY, E., DALY, H., HOWLEY, M. & O GALLACHOIR, B. P. 2011. Impacts of an emission based private car taxation policy – First year ex-post analysis. *Transportation Research Part A: Policy and Practice.*45**,** 583-597.
ROJAS-RUEDA, D., DE NAZELLE, A., TAINIO, M. & NIEUWENHUIJSEN, M. J. 2011. The health risks and benefits of cycling in urban environments compared with car use: health impact assessment study. *BMJ,* 343**,** d4521.
ROSENBERG, E., FIDJE, A., ESPEGREN, K. A., STILLER, C., SVENSSON, A. M. & MØLLER-HOLST, S. 2010. Market penetration analysis of hydrogen vehicles in Norwegian passenger transport towards 2050. *International Journal of Hydrogen Energy,* 35**,** 7267-7279.
ROTARIS, L. & DANIELIS, R. 2014. The impact of transportation demand management policies on commuting to college facilities: A case study at the University of Trieste, Italy. *Transportation Research Part A: Policy and Practice,* 67**,** 127-140.
ROTARIS, L., DANIELIS, R., MARCUCCI, E. & MASSIANI, J. 2010. The urban road pricing scheme to curb pollution in Milan, Italy: Description, impacts and preliminary cost–benefit analysis assessment. *Transportation Research Part A: Policy and Practice.*44.
SADLER CONSULTANTS LTD 2015. Available: www.urbanaccessregulations.eu [Accessed May 2016].
SAHU, M., HU, S., RYAN, P. H., LE MASTERS, G., GRINSHPUN, S. A., CHOW, J. C. & BISWAS, P. 2011. Chemical compositions and source identification of PM(2).(5) aerosols for estimation of a diesel source surrogate. *Sci Total Environ,* 409**,** 2642-51.
SAIDUR, R., REZAEI, M., MUZAMMIL, W. K., HASSAN, M. H., PARIA, S. & HASANUZZAMAN, M. 2012. Technologies to recover exhaust heat from internal combustion engines. *Renewable and Sustainable Energy Reviews,* 16**,** 5649-5659.
SAIKKONEN, L., OLLIKAINEN, M. & LANKOSKI, J. 2014. Imported palm oil for biofuels in the EU: Profitability, greenhouse gas emissions and social welfare effects. *Biomass and Bioenergy.*68**,** 7-23.
SALEM, S., SALEM, A. & BABAEI, A. A. Application of Iranian nano-porous Ca-bentonite for recovery of waste lubricant oil by distillation and adsorption techniques. *Journal of Industrial and Engineering Chemistry*.
SANTI, P., RESTA, G., SZELL, M., SOBOLEVSKY, S., STROGATZ, S. H. & RATTI, C. 2014. Quantifying the benefits of vehicle pooling with shareability networks. *Proc Natl Acad Sci U S A.* 2014/09/10 ed.111**,** 13290-4.
SANTOS, G., BEHRENDT, H., MACONI, L., SHIRVANI, T. & TEYTELBOYM, A. 2010. Part I: Externalities and economic policies in road transport. *Research in Transportation Economics.*28**,** 2-45.
SCAHDE, J., SCHLAG, B. 2002. Acceptability of urban transport pricing strategies. *Transportation Research Part F: Traffic Psychology and Behaviour.*6**,** 45–61.
SCHAECK, S., STOERMER, A. O., KAISER, F., KOEHLER, L., ALBERS, J. & KABZA, H. 2011. Lead-acid batteries in micro-hybrid applications. Part I. Selected key parameters. *Journal of Power Sources,* 196**,** 1541-1554.

SCHIPPLE, J. & PUHE, M. 2012. Description of technologies, challenges and paradigms in urban transport. Report to the European Parliament, Brussels. Available: http://www.europarl.europa.eu/RegData/etudes/etudes/join/2012/482692/IPOL-JOIN_ET(2012)482692(ANN02)_EN.pdf.

SCHÖNAUER, D., SICHERT, I. & MOOS, R. 2011. Vanadia doped tungsten–titania SCR catalysts as functional materials for exhaust gas sensor applications. *Sensors and Actuators B: Chemical.*155**,** 199-205.

SCHUITEMA, G., STEG, L. & FORWARD, S. 2010. Explaining differences in acceptability before and acceptance after the implementation of a congestion charge in Stockholm. *Transportation Research Part A: Policy and Practice.*44.

SCHWEINFURTH, A. 2009. Car-scrapping schemes: An effective economic rescue policy? *The Global Subsidies Initiative*. Available: http://www.iisd.org/library/car-scrapping-schemes-effective-economic-rescue-policy [Accessed May 2016].

SCHWEITZER, L., BRODRICK, C.-J. & SPIVEY, S. E. 2008. Truck driver environmental and energy attitudes – an exploratory analysis. *Transportation Research Part D: Transport and Environment.*13**,** 141-150.

SEITZ, M. A. 2007. A critical assessment of motives for product recovery: the case of engine remanufacturing. *Journal of Cleaner Production,* 15**,** 1147-1157.

SENIOR, M. L. 2008. Impacts on travel behaviour of Greater Manchester's light rail investment (Metrolink Phase 1): evidence from household surveys and Census data. . *Journal of Transport Geography,* 17**,** 187-197.

SHEN, W., HAN, W., CHOCK, D., CHAI, Q. & ZHANG, A. 2012. Well-to-wheels life-cycle analysis of alternative fuels and vehicle technologies in China. *Energy Policy,* 49**,** 296-307.

SHIAU, C.-S. N., SAMARAS, C., HAUFFE, R. & MICHALEK, J. J. 2009. Impact of battery weight and charging patterns on the economic and environmental benefits of plug-in hybrid vehicles. *Energy Policy,* 37**,** 2653-2663.

SHOUP, D. 2005. *The High Cost of Free Parking*, Planners Press.

SILVA, C. 2013. At what extent the benefits of introducing alternative light-duty vehicles offset those of increasing the buses average occupancy? *Energy Conversion and Management.*70**,** 211-219.

SILVA, C. & FARIAS, T. 2010. CHAPTER SEVEN - Evaluation of Energy Consumption, Emissions, and Costs of Plug-in Hybrid Vehicles. *In:* PISTOIA, G. (ed.) *Electric and Hybrid Vehicles.* Amsterdam: Elsevier.

SILVA-SEND, N., ANDERS, S. & NARWOLD, A. 2013. Cost effectiveness comparison of certain transportation measures to mitigate greenhouse gas emissions in San Diego County, California. *Energy Policy.*62**,** 1428-1433.

SINCLAIR, C., O'CONNOR, S. & CONNOLLY, D. 2013. Sheffield Air Quality Modelling Low Emission Zone (LEZ) Feasibility Study, Phase 2 - Final Report. Available: https://www.sheffield.gov.uk/dms/scc/management/corporate-communications/documents/environment/pollution/air/Low-Emission-Zone-Feasibility-Study---Phase-2-Individual-Cabinet-Report/Low%20Emission%20Zone%20Feasibility%20Study%20-%20Phase%202%20Individual%20Cabinet%20Report.pdf [Accessed May 2016].

SIOSHANSI, R., FAGIANI, R. & MARANO, V. 2010. Cost and emissions impacts of plug-in hybrid vehicles on the Ohio power system. *Energy Policy,* 38**,** 6703-6712.

SLOMAN, L., CAIRNS, S., NEWSON, C., ANABLE, J., PRIDMORE, A. & GOODWIN, P. 2010. The Effects of Smarter Choice Programmes in the Sustainable Travel Towns: Summary Report. A report to the Department for Transport. Available: http://webarchive.nationalarchives.gov.uk/20111005180138/http://assets.dft.gov.uk/publications/the-effects-of-smarter-choice-programmes-in-the-sustainable-travel-towns-summary-report/summaryreport.pdf.

SMALL, K. A. 2012. Energy policies for passenger motor vehicles. *Transportation Research Part A: Policy and Practice.*46**,** 874-889.

SMITH, M. J. T. 2000. 'Hushkits' — re-certificated aircraft and the environment : An opinion. *Air & Space Europe,* 2**,** 18-24.

SMITH, W. J. 2010a. Can EV (electric vehicles) address Ireland's CO2 emissions from transport? *Energy,* 35**,** 4514-4521.

SMITH, W. J. 2010b. Plug-in hybrid electric vehicles—A low-carbon solution for Ireland? *Energy Policy,* 38**,** 1485-1499.

SMMT 2014a. MVRIS Car Market Segment and Sales Type. . *http://www.smmt.co.uk/wp-content/uploads/sites/2/MVRIS-Car-Market-Segment-and-Sales-Type.pdf [Accessed 05/11/2014].*

SMMT 2014b. New car registrations pass two million in 2014 with October surge. . *http://www.smmt.co.uk/2014/11/new-car-registrations-october-2014/ [Accessed 05/11/2014]*

SMMT (THE SOCIETY OF MOTOR MANUFACTURERS AND TRADER'S) 2010. 11th Sustainability Report (2010). Available: http://www.smmt.co.uk/2010/10/eleventh-sustainability-report-2010/.

SORRENTINO, M., RIZZO, G. & SORRENTINO, L. 2014. A study aimed at assessing the potential impact of vehicle

electrification on grid infrastructure and road-traffic green house emissions. *Applied Energy,* 120**,** 31-40.
SPIES, J. 2003. RLV Hopper: Consolidated system concept. *Acta Astronautica,* 53**,** 709-717.
SPINELLI, R. & MAGAGNOTTI, N. 2014. Determining long-term chipper usage, productivity and fuel consumption. *Biomass and Bioenergy,* 66**,** 442-449.
SPITZLEY, D. V., GRANDE, D. E., KEOLEIAN, G. A. & KIM, H. C. 2005. Life cycle optimization of ownership costs and emissions reduction in US vehicle retirement decisions. *Transportation Research Part D: Transport and Environment.*10**,** 161-175.
SQW 2013. UK Broadband Impact Study. Available: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/257006/UK_Broadband_Impact_Study_-_Impact_Report_-_Nov_2013_-_Final.pdf [Accessed 18 December 2013].
STAMOS, I., KITIS, G., BASBAS, S. & TZEVELEKIS, I. 2012. Evaluation of a High Occupancy Vehicle Lane in Central Business District Thessaloniki. *Procedia - Social and Behavioral Sciences.*48**,** 1088-1096.
STASKO, T. H. & OLIVER GAO, H. 2012. Developing green fleet management strategies: Repair/retrofit/replacement decisions under environmental regulation. *Transportation Research Part A: Policy and Practice,* 46**,** 1216-1226.
STEININGER, K. W., FRIEDL, B. & GEBETSROITHER, B. 2007. Sustainability impacts of car road pricing: A computable general equilibrium analysis for Austria. *Ecological Economics.*63**,** 59-69.
STEPHENS-ROMERO, S. D., BROWN, T. M., KANG, J. E., RECKER, W. W. & SAMUELSEN, G. S. 2010. Systematic planning to optimize investments in hydrogen infrastructure deployment. *International Journal of Hydrogen Energy,* 35**,** 4652-4667.
STERNER, T. 2007. Fuel taxes: An important instrument for climate policy. *Energy Policy.*35**,** 3194-3202.
STERNER, T. 2012. Distributional effects of taxing transport fuel. *Energy Policy.*41**,** 75-83.
STRECKER, B., HAUSMANN, A. & DEPCIK, C. 2014. Well to wheels energy and emissions analysis of a recycled 1974 VW Super Beetle converted into a plug-in series hybrid electric vehicle. *Journal of Cleaner Production,* 68**,** 93-103.
SUN, H., SI, B. & WU, J. 2008. Combined Model for Flow Assignment and Mode Split in Two-modes Traffic Network. *Journal of Transportation Systems Engineering and Information Technology,* 8**,** 77-82.
SUSTAINABILITY MANAGEMENT CAPSTONE, C. U. 2013. C40 Cities in action: How Bike-share amd BRT are accelerating accross the world. 132. Available: http://sustainability.ei.columbia.edu/files/2014/01/C40-CITIES-IN-ACTION_Fall-2013-.pdf [Accessed May 2013].
SUSTRANS 2013. Personalised Travel Planning. Available: http://www.sustrans.org.uk/our-services/what-we-do/personalised-travel-planning [Accessed 18 December 2013].
TAKESHITA, T. 2011. Global scenarios of air pollutant emissions from road transport through to 2050. *Int J Environ Res Public Health.* 2011/08/17 ed.8**,** 3032-62.
TARROJA, B., EICHMAN, J. D., ZHANG, L., BROWN, T. M. & SAMUELSEN, S. 2014. The effectiveness of plug-in hybrid electric vehicles and renewable power in support of holistic environmental goals: Part 1 – Evaluation of aggregate energy and greenhouse gas performance. *Journal of Power Sources,* 257**,** 461-470.
TATE, J. 2013. Vehicle Emission Measurement and Analysis - Cambridge City Council. Available: https://www.cambridge.gov.uk/sites/default/files/documents/Cam_VEMS_ProjectReport_v1.0.pdf [Accessed May 2016].
TEO, J. S. E., TANIGUCHI, E. & QURESHI, A. G. 2014. Evaluation of Load Factor Control and Urban Freight Road Pricing Joint Schemes with Multi-agent Systems Learning Models. *Procedia - Social and Behavioral Sciences.*125**,** 62-74.
THIEL, C., SCHMIDT, J., VAN ZYL, A. & SCHMID, E. 2014. Cost and well-to-wheel implications of the vehicle fleet CO2 emission regulation in the European Union. *Transportation Research Part A: Policy and Practice.*63**,** 25-42.
THOMAS, B. A. & AZEVEDO, I. L. 2014. Should policy-makers allocate funding to vehicle electrification or end-use energy efficiency as a strategy for climate change mitigation and energy reductions? Rethinking electric utilities efficiency programs. *Energy Policy,* 67**,** 28-36.
THOMAS, C. E. 2012. US marginal electricity grid mixes and EV greenhouse gas emissions. *International Journal of Hydrogen Energy,* 37**,** 19231-19240.
THORMÄHLEN, P., FRIDELL, E., CRUISE, N., SKOGLUNDH, M. & PALMQVIST, A. 2001. The influence of CO2, C3H6, NO, H2, H2O or SO2 on the low-temperature oxidation of CO on a cobalt-aluminate spinel catalyst (Co1.66Al1.34O4). *Applied Catalysis B: Environmental,* 31**,** 1-12.
TIRACHINI, A., HENSHER, D. A. & ROSE, J. M. 2014. Multimodal pricing and optimal design of urban public transport: The interplay between traffic congestion and bus crowding. *Transportation Research Part B: Methodological,* 61**,** 33-54.
TNO 2006. The Effects of a Range of Measures to Reduce the Tail Pipe Emissions and/or the Fuel Consumption of

Modern Passenger Cars on Petrol and Diesel. Available: http://www.ecodrive.org/fileadmin/dam/ecodrive/Downloads/TNO-rapport_HNR_GSI_en_emissies_2006.pdf [Accessed 18 December 2013].

TONNE, C., BEEVERS, S., ARMSTRONG, B., KELLY, F. & WILKINSON, P. 2008. Air pollution and mortality benefits of the London Congestion Charge: spatial and socioeconomic inequalities. *Occup Environ Med,* 65**,** 620-7.

TONNE, C., BEEVERS, S., ARMSTRONG, B., KELLY, F. & WILKINSON, P. 2008. Air pollution and mortality benefits of the London Congestion Charge: spatial and socioeconomic inequalities. *Occup Environ Med.*65**,** 620-7.

TONNE, C., BEEVERS, S., KELLY, F. J., JARUP, L., WILKINSON, P. & ARMSTRONG, B. 2010. An approach for estimating the health effects of changes over time in air pollution: an illustration using cardio-respiratory hospital admissions in London. *Occup Environ Med.*67**,** 422-7.

TORRES, J. L., GONZALEZ, R., GIMENEZ, A. & LOPEZ, J. 2014. Energy management strategy for plug-in hybrid electric vehicles. A comparative study. *Applied Energy,* 113**,** 816-824.

TRANSPORT AND ENVIRONMENT 2013. Mind the Gap! Why official car fuel economy figures don't match up to reality. *http://www.transportenvironment.org/publications/mind-gap-why-official-car-fuel-economy-figures-don%E2%80%99t-match-reality [Accessed 05/11/2014].*

TRANSPORT FOR GREATER MANCHESTER 2006. Reducing the impacts of air pollution from transport on health and well-being. Available: http://www.tfgm.com/ltp3/Documents/Air-Quality-Strategy-and-Action-Plan.pdf [Accessed May 2016].

TRANSPORT FOR GREATER MANCHESTER 2011. 2011/2012 Annual Report: Connecting Greater Manchester. Available: http://www.tfgm.com/Corporate/Documents/AnnualReportsBusinessPerformancePlans/11-0909-Ann_Performance-Report-AW.pdf.

TRANSPORT FOR LONDON 2009. A pilot Delivery and Servicing Plan for TfL's Palestra Offices in Southwark: A London Freight Matters Case Study Available: https://tfl.gov.uk/cdn/static/cms/documents/dsp-palestra-case-study.pdf.

TRANSPORT FOR LONDON 2010. Travel in London, Report 3, Transport for London. Available: http://www.tfl.gov.uk/assets/downloads/corporate/travel-in-london-report-3.pdf [Accessed 18 December 2013].

TRANSPORT FOR LONDON 2014. Available: www.tfl.gov.uk/info-for/media/press-releases/2014/september/mayor-and-tfl-expand-europe-s-greenest-bus-fleet [Accessed September 2014].

TRANSPORT FOR LONDON 2015. Available: https://tfl.gov.uk/modes/driving/ultra-low-emission-zone [Accessed May 2016].

TRETVIK, T., NORDTØMME, M. E., BJERKAN, K. Y. & KUMMENEJE, A.-M. 2014. Can low emission zones be managed more dynamically and effectively? *Research in Transportation Business & Management.*

TSAI, Y. I., YANG, H. ET AL. 2011. The Influences of Diesel Particulate Filter Installation on Air Pollutant Emissions for Used Vehicles. *Aerosol and Air Quality Research.* 11**,** 578–583.

TSCHARAKTSCHIEW, S. Shedding light on the appropriateness of the (high) gasoline tax level in Germany. *Economics of Transportation.*

UK HOUSE OF COMMONS 2005. "Passenger Transport (Fuel Consumption)". . *Hansard Parliamentary Debates, Column 1800W, 20/07/2005. www.publications.parliament.uk/pa/cm200506/cmhansrd/vo050720/text/50720w26.htm#50720w26.html*

UNEP 2013. United Nations Environment Programme: Transport. Available: http://www.unep.org/transport/About.asp [Accessed May 2016].

UNGER, N., SHINDELL, D. T. & WANG, J. S. 2009. Climate forcing by the on-road transportation and power generation sectors. *Atmospheric Environment,* 43**,** 3077-3085.

VAN DEN BERG, V. & VERHOEF, E. T. 2011. Winning or losing from dynamic bottleneck congestion pricing?: The distributional effects of road pricing with heterogeneity in values of time and schedule delay. *Journal of Public Economics.*95**,** 983-992.

VAN VLIET, O., BROUWER, A. S., KURAMOCHI, T., VAN DEN BROEK, M. & FAAIJ, A. 2011. Energy use, cost and CO2 emissions of electric cars. *Journal of Power Sources,* 196**,** 2298-2310.

VAN WOENSEL, T. & CRUZ, F. R. B. 2009. A stochastic approach to traffic congestion costs. *Computers & Operations Research.*36**,** 1731-1739.

VEDAGIRI, P. & ARASAN, V. T. 2009. Estimating Modal Shift of Car Travelers to Bus on Introduction of Bus Priority System. *Journal of Transportation Systems Engineering and Information Technology.*9**,** 120-129.

VIEGAS, J. & LU, B. 2004. The Intermittent Bus Lane signals setting within an area. *Transportation Research Part C: Emerging Technologies,* 12**,** 453-469.

VINEIS, P., HOEK, G., KRZYZANOWSKI, M., VIGNA-TAGLIANTI, F., VEGLIA, F., AIROLDI, L., OVERVAD, K., RAASCHOU-NIELSEN, O., CLAVEL-CHAPELON, F., LINSEISEN, J., BOEING, H., TRICHOPOULOU, A., PALLI, D., KROGH, V., TUMINO, R., PANICO, S., BUENO-DE-MESQUITA, H. B., PEETERS, P. H., LUND, E. E., AGUDO,

A., MARTINEZ, C., DORRONSORO, M., BARRICARTE, A., CIRERA, L., QUIROS, J. R., BERGLUND, G., MANJER, J., FORSBERG, B., DAY, N. E., KEY, T. J., KAAKS, R., SARACCI, R. & RIBOLI, E. 2007. Lung cancers attributable to environmental tobacco smoke and air pollution in non-smokers in different European countries: a prospective study. *Environ Health,* 6**,** 7.

VOGEL, M., HAMON, R., LOZENGUEZ, G., MERCHEZ, L., ABRY, P., BARNIER, J., BORGNAT, P., FLANDRIN, P., MALLON, I. & ROBARDET, C. 2014. From bicycle sharing system movements to users: a typology of Vélo'v cyclists in Lyon based on large-scale behavioural dataset. *Journal of Transport Geography*.

VON STORCH, H., COSTA-CABRAL, M., HAGNER, C., FESER, F., PACYNA, J., PACYNA, E. & KOLB, S. 2003. Four decades of gasoline lead emissions and control policies in Europe: a retrospective assessment. *Sci Total Environ,* 311**,** 151-76.

VONK NOORDEGRAAF, D., ANNEMA, J. A. & VAN WEE, B. 2014. Policy implementation lessons from six road pricing cases. *Transportation Research Part A: Policy and Practice.*59**,** 172-191.

VUKOVIC, G., ANICIC UROSEVIC, M., RAZUMENIC, I., GORYAINOVA, Z., FRONTASYEVA, M., TOMASEVIC, M. & POPOVIC, A. 2013. Active moss biomonitoring of small-scale spatial distribution of airborne major and trace elements in the Belgrade urban area. *Environ Sci Pollut Res Int,* 20**,** 5461-70.

WADUD, Z. New vehicle fuel economy in the UK: Impact of the recession and recent policies. *Energy Policy*.

WAGNER, V. & RUTHERFORD, D. 2013. Survey of best practice in emission control of in-use heavy duty diesel vehicles. . *The International Council on Clean Transportation, Washington*.

WAHLSTEDT, J. 2011. Impacts of Bus Priority in Coordinated Traffic Signals. *Procedia - Social and Behavioral Sciences.*16**,** 578-587.

WALSALL COUNCIL 2007. Assessment of Air Quality, M6 Toll Road - Nitrogen Dioxide and Particulate Matter (PM_{10}). Available: file:///C:/Users/AF7/Downloads/m6_toll_road_air_quality_report_may_2007.pdf [Accessed May 2016].

WANG, H., FU, L. & CHEN, J. 2010. Developing a high-resolution vehicular emission inventory by integrating an emission model and a traffic model: Part 2--A case study in Beijing. *J Air Waste Manag Assoc,* 60**,** 1471-5.

WANG, J. & SUN, G. 2010. Combinatorial Optimization of Congested Road and Parking Charging. *Journal of Transportation Systems Engineering and Information Technology,* 10**,** 24-28.

WANG, L., ZHANG, Y., YIN, C., ZHANG, H. & WANG, C. 2012. Hardware-in-the-loop simulation for the design and verification of the control system of a series–parallel hybrid electric city-bus. *Simulation Modelling Practice and Theory.*25**,** 148-162.

WANG, T., ZHANG, Y., PENG, Z. & SHU, G. 2011. A review of researches on thermal exhaust heat recovery with Rankine cycle. *Renewable and Sustainable Energy Reviews,* 15**,** 2862-2871.

WANG, W., HUSSIN, B. & JEFFERIS, T. 2012. A case study of condition based maintenance modelling based upon the oil analysis data of marine diesel engines using stochastic filtering. *International Journal of Production Economics,* 136**,** 84-92.

WANG, X., FENG, C., DING, N., ZHANG, Q., LI, N., LI, X., ZHANG, Y. & ZHOU, Q. 2014. Accelerated OH(-) transport in activated carbon air cathode by modification of quaternary ammonium for microbial fuel cells. *Environ Sci Technol,* 48**,** 4191-8.

WEISS, M., BONNEL, P., KÜHLWEIN, J., PROVENZA, A., LAMBRECHT, U., ALESSANDRINI, S., CARRIERO, M., COLOMBO, R., FORNI, F., LANAPPE, G., LE LIJOUR, P., MANFREDI, U., MONTIGNY, F. & SCULATI, M. 2012. Will Euro 6 reduce the NOx emissions of new diesel cars? – Insights from on-road tests with Portable Emissions Measurement Systems (PEMS). *Atmospheric Environment.*62**,** 657-665.

WELCH, T. F. & MISHRA, S. 2014. A framework for determining road pricing revenue use and its welfare effects. *Research in Transportation Economics.*44**,** 61-70.

WESTBROOK, J., BARTER, G. E., MANLEY, D. K. & WEST, T. H. 2014. A parametric analysis of future ethanol use in the light-duty transportation sector: Can the US meet its Renewable Fuel Standard goals without an enforcement mechanism? *Energy Policy,* 65**,** 419-431.

WILSON, A. & COPE, A. 2011. Value for money of walking and cycling interventions: Making the case for investiment in active travel. Available: http://www.starconference.org.uk/star/2011/angelaWilson.pdf [Accessed May 2016].

WOODCOCK, J., TAINIO, M., CHESHIRE, J., O'BRIEN, O. & GOODMAN, A. 2014. Health effects of the London bicycle sharing system: health impact modelling study. *BMJ.* 14.

WORKWISE 2013. Home Working Defies Recession. Available: http://www.workwiseuk.org/news/?item=home-working-defies-recession [Accessed 18 December 2013].

WORLD ENERGY TECHNOLOGY OUTLOOK WETO H2. European Commission, World Energy Technology Outlook – 2050 (WETO-H2), 2006 Luxembourg.

WU, J., TJOA, T., LI, L., JAIMES, G. & DELFINO, R. J. 2012. Modeling personal particle-bound polycyclic aromatic hydrocarbon (pb-pah) exposure in human subjects in Southern California. *Environ Health.* 2012/07/13 ed.11**,** 47.

WU, Y., YANG, Z., LIN, B., LIU, H., WANG, R., ZHOU, B. & HAO, J. 2012. Energy consumption and CO2 emission impacts of vehicle electrification in three developed regions of China. *Energy Policy,* 48**,** 537-550.

XIONG, P. 2010. Park and Ride Behaviors for Non-Local Private Car Travelers in Big Events. *Journal of Transportation Systems Engineering and Information Technology,* 10**,** 188-193.

YABE, K., SHINODA, Y., SEKI, T., TANAKA, H. & AKISAWA, A. 2012. Market penetration speed and effects on CO2 reduction of electric vehicles and plug-in hybrid electric vehicles in Japan. *Energy Policy,* 45**,** 529-540.

YAMAMOTO, T., MADRE, J.-L. & KITAMURA, R. 2004. An analysis of the effects of French vehicle inspection program and grant for scrappage on household vehicle transaction. *Transportation Research Part B: Methodological.*38**,** 905-926.

YAN, X. & CROOKES, R. J. 2009. Reduction potentials of energy demand and GHG emissions in China's road transport sector. *Energy Policy.*37**,** 658-668.

YANG, C. 2013. Fuel electricity and plug-in electric vehicles in a low carbon fuel standard. *Energy Policy,* 56**,** 51-62.

YAZDANIE, M., NOEMBRINI, F., DOSSETTO, L. & BOULOUCHOS, K. 2014. A comparative analysis of well-to-wheel primary energy demand and greenhouse gas emissions for the operation of alternative and conventional vehicles in Switzerland, considering various energy carrier production pathways. *Journal of Power Sources,* 249**,** 333-348.

YE, X. & MA, W. 2013. Influence of Access Traffic on the Operational Efficiencies of Bus Lane and Main Road. *Procedia - Social and Behavioral Sciences,* 96**,** 1648-1658.

YIN, Y. & LAWPHONGPANICH, S. 2006. Internalizing emission externality on road networks. *Transportation Research Part D: Transport and Environment.*11**,** 292-301.

YOSHIDA, K. 2013. Diesel NOx aftertreatment by combined process using temperature swing adsorption, nonthermal plasma, and NOx recirculation: NOx removal accelerated by conversion of NO to NO2. *Journal of the Taiwan Institute of Chemical Engineers.*44**,** 1054-1059.

YOSHIDA, K., KUWAHARA, T., KUROKI, T. & OKUBO, M. 2012. Diesel NOx aftertreatment by combined process using temperature swing adsorption, NOx reduction by nonthermal plasma, and NOx recirculation: Improvement of the recirculation process. *Journal of Hazardous Materials.*231–232**,** 18-25.

YOSHIDA, Y., DOWAKI, K., MATSUMURA, Y., MATSUHASHI, R., LI, D., ISHITANI, H. & KOMIYAMA, H. 2003. Comprehensive comparison of efficiency and CO2 emissions between biomass energy conversion technologies—position of supercritical water gasification in biomass technologies. *Biomass and Bioenergy,* 25**,** 257-272.

YU, S. & TAO, J. 2009. Simulation-based life cycle assessment of energy efficiency of biomass-based ethanol fuel from different feedstocks in China. *Energy,* 34**,** 476-484.

ZACHARIADIS, T., NTZIACHRISTOS, L. & SAMARAS, Z. 2001. The effect of age and technological change on motor vehicle emissions. *Transportation Research Part D: Transport and Environment.*6**,** 221-227.

ZAMEL, N. & LI, X. 2006. Life cycle analysis of vehicles powered by a fuel cell and by internal combustion engine for Canada. *Journal of Power Sources,* 155**,** 297-310.

ZEKA, A., MELLY, S. J. & SCHWARTZ, J. 2008. The effects of socioeconomic status and indices of physical environment on reduced birth weight and preterm births in Eastern Massachusetts. *Environ Health,* 7**,** 60.

ZENITH 2014. Company Car Tax. *https://www.zenith.co.uk/customerDocs/public/CompanyCarTax.pdf [Accessed 05/11/2014]*.

ZHANG, S., WU, Y., WU, X., LI, M., GE, Y., LIANG, B., XU, Y., ZHOU, Y., LIU, H., FU, L. & HAO, J. 2014. Historic and future trends of vehicle emissions in Beijing, 1998–2020: A policy assessment for the most stringent vehicle emission control program in China. *Atmospheric Environment.*89**,** 216-229.

ZHANG, X., HUANG, H.-J. & ZHANG, H. M. 2008. Integrated daily commuting patterns and optimal road tolls and parking fees in a linear city. *Transportation Research Part B: Methodological.*42**,** 38-56.

ZHANG, X., HUANG, H.-J. & ZHANG, H. M. 2008. Integrated daily commuting patterns and optimal road tolls and parking fees in a linear city. *Transportation Research Part B: Methodological,* 42**,** 38-56.

ZHAO, H., YAN, X. & GAO, Z. 2013. Transportation serviceability analysis for metropolitan commuting corridors based on modal choice modeling. *Transportation Research Part A: Policy and Practice,* 49**,** 270-284.

ZOLNIK, E. J. 2012. Estimates of statewide and nationwide carbon dioxide emission reductions and their costs from Cash for Clunkers. *Journal of Transport Geography.*24**,** 271-281.

Annex

A.1 Annex 1: Initial list of potential policy measures

Table 9: List of potential policy measures

Measure type	Measure	Application	Policy type	Area	Theme	Section in report where considered
Reduce demand for more polluting forms of transport	Promote freight modal shift	Freight/HGVs/LGVs	Funding	National	Pricing mechanisms	2.2.4
	Lorry road user charging	Freight/HGVs/LGVs	Taxation	National	Pricing mechanisms	2.2.6
	Subsidising public transport	Buses	Funding	National	Pricing mechanisms	2.2.6
	Provision of school buses	Buses	Funding	Local	Other	2.2
	Designating new and priority bus measures	Buses	Funding	Local	LEZ	2.2
	Promote walking and cycling	Cars	Funding	Local	Other	2.2.2
	Promote car sharing	Cars	Funding	Local	Pricing mechanisms	2.2.5
	Workplace charging levies	Cars	Taxation	Local	Pricing mechanisms	2.2.6
	High occupancy vehicle lanes	Cars	Regulation	Local	LEZ	2.3.4
	National road pricing	Congestion	Taxation	National	Pricing mechanisms	2.2.6
	Local congestion charging	Congestion	Taxation	Local	LEZ	2.2.6
	Promote tele-working/video conferencing	Other	Guidance/info	National	Other	2.2.3
	Increase fuel duty/target at diesels	Other	Taxation	National	Pricing mechanisms	2.2.6
	New tram schemes	Other	Infrastructure	Local	Other	2.2
	Travel planning	Other	Guidance/info	Local	Other	2.2.2
Reduce emissions from existing vehicles	Allow more night time freight delivery	Freight/HGVs/LGVs	Regulation	Local	Other	2.2.4
	Lorry overtaking bans	Freight/HGVs/LGVs	Regulation	Local	Other	2.3.5
	Promote DeNOx retrofit	Freight/HGVs/LGVs	Funding	National	Retrofitting	2.4
	Promote Eco driving	Freight/HGVs/LGVs	Guidance/info	National	Other	2.4.1
	Promote Eco driving	Buses	Guidance/info	National	Other	2.4.1
	Promote Eco driving	Cars	Guidance/info	National	Other	2.4.1
	Annual vehicle emissions tests	Freight/HGVs/LGVs	Regulation	National	Other	2.4
	Annual vehicle emissions tests	Buses	Regulation	National	Other	2.4
	Annual vehicle emissions tests	Cars	Regulation	National	Other	2.4

	Roadside vehicle emissions tests	Freight/HGVs/LGVs	Regulation	Local	Other	2.4
	Roadside vehicle emissions tests	Buses	Regulation	Local	Other	2.4
	Roadside vehicle emissions tests	Cars	Regulation	Local	Other	2.4
	Pedestrian walkways over trunk roads	Congestion	Infrastructure	Local	Other	2.2
	Designating new and priority bus measures	Buses	Funding	Local	LEZ	2.2
	New managed motorways	Congestion	Infrastructure	Local	Other	2.3.5
	Active traffic light management	Congestion	Funding	Local	Other	2.3.5
	Intelligent speed adaptation	Congestion	Funding	Local	Other	2.3.5
	Ramp metering	Other	Funding	Local	Other	2.3.5
	Lower motorway speed limits	Other	Regulation	Local	LEZ	2.3.5
	Improved junction layout	Other	Infrastructure	Local	Other	2.3.5
	Better traffic management	Other	Guidance/info	Local	Other	2.3.5
	Strengthen air quality planning regulations	Other	Regulation	National	Other	2.2.1
	improved anti-idling enforcement	Other	Regulation	Local	LEZ	2.3.5
Promote cleaner vehicles	HGV scrappage	Freight/HGVs/LGVs	Funding	National	Scrappage	2.4
	Fleet recognition schemes	Freight/HGVs/LGVs	Guidance/info	Local	Other	2.4
	Negotiate new vehicle emission standards	Freight/HGVs/LGVs	Regulation	National	Other	2.4
	Negotiate new vehicle emission standards	Buses	Regulation	National	Other	2.4
	Reduced VED for early purchase of new vehicles	Freight/HGVs/LGVs	Taxation	National	Pricing mechanisms	2.4
	Reduced VED for early purchase of new vehicles	Buses	Taxation	National	Pricing mechanisms	2.4
	Promotion of Low Emission Zones	Freight/HGVs/LGVs	Regulation	Local	LEZ	2.3.2
	Promotion of Low Emission Zones	Buses	Regulation	Local	LEZ	2.3.2
	Bus scrappage	Buses	Funding	National	Scrappage	2.4
	Grants to buy new low emission buses	Buses	Funding	Local	Pricing mechanisms/Scrappage	2.2.6/2.4
	Bus operator NOx emissions cap	Buses	Regulation	Local	Pricing mechanisms	2.4
	Priority parking for low emissions vehicles	Cars	Regulation	Local	Pricing mechanisms	2.3.3
	Pollution car labelling scheme	Cars	Guidance/info	National	Other	2.4
	Grants for purchase of ultra-low emission cars	Cars	Funding	National	Pricing mechanisms	2.2.6
	Allow low emission cars to use bus lanes	Cars	Regulation	Local	LEZ	2.3.1

Displace pollutant emissions outside hot spots and populated areas	Fiscal incentives for low emission vehicles	Cars	Taxation	National	Pricing mechanisms	2.2.6
	Development of EV charging infrastructure	Cars	Infrastructure	Local	Pricing mechanisms	2.4
	Rail electrification	Other	Infrastructure	Local	Other	2.4
	Reduced shipping emission	Other	Regulation	National	Other	2.4
	Public procurement of cleaner vehicles	Other	Funding	Local	Pricing mechanisms	2.4
	Promote AQ beneficial bio-fuels	Other	Funding	Local	Pricing mechanisms	2.4
	Public information campaign to promote cleaner vehicles	Other	Guidance/info	National	Other	2.4
	Lorry ban in urban centres	Freight/HGVs/LGVs	Regulation	Local	LEZ	2.3.1
	Freight consolidation centres	Freight/HGVs/LGVs	Regulation	Local	LEZ	2.2.4
	Restricted access zones	Freight/HGVs/LGVs	Regulation	Local	LEZ	2.3.1
	Restricted access zones	Buses	Regulation	Local	LEZ	2.3.1
	Restricted access zones	Cars	Regulation	Local	LEZ	2.3.1
	Newer buses used for most polluted routes	Buses	Regulation	Local	LEZ	2.4
	Queue relocation	Congestion	Funding	Local	Other	2.3.4
	New roads	Other	Infrastructure	Local	Other	2.3.4
	NOx absorbing coatings	Other	Infrastructure	Local	Other	Eliminated
	Planting trees along roadsides	Other	Infrastructure	Local	Other	Eliminated
	Redevelopment of polluted sites	Other	Funding	Local	Other	2.2.1

NOx absorbing coatings are currently being reviewed by AQEG on behalf of Defra. This was investigated previously and concluded that insignificant impact at a widespread scale were likely. http://laqm.defra.gov.uk/laqm-faqs/faq42.html

Planting trees along roadsides has been investigated previously and it was determined there was a potential local scale barrier impact. As this measure is limited in the geographical scale of its impact it has not been considered further but it is recognised that green infrastructure is a supportive measure to reduce pollution in urban areas http://laqm.defra.gov.uk/laqm-faqs/faq41.html

A.2 Annex 2 – Methodology - Search Terms and Criteria

Methodology

The Civil Service guidance on Rapid Evidence Assessment[8] and the guidance prepared by the Joint Water Evidence Group on 'The Production of Quick Scoping Reviews and Rapid Evidence Assessments: A How to Guide' have been followed in the review when appropriate.

Sources of literature

The literature search included the following two strands of UK, European and international sources:

- On-line database (Science Direct, PubMed, Scopus) of published scientific articles
- Grey literature (reports) identified through publicly available websites, the reference library of the Project team, contacting relevant organisations (e.g. GLA, TfL, SEPA, Transport Scotland, Devolved Administrations) and the EC catalogue of air quality measures[9]

Search strategy - screening and ranking of articles

The literature search through the use of on-line databases generated a large number of articles. The number of articles was reduced to a more manageable number by applying the search terms for a policy measure, together with different Boolean operations of the search term for an area of application (e.g. only vehicles) and a policy outcome (e.g. air pollution or journeys). The articles identified were then screened using a staged approach. This was completed in duplicate with all papers included as a result of the initial screening being brought into a combined endnote library

Science Direct was used as the primary on-line database to identify articles published after the year 2000. The search engines, PubMed and Scopus, were later used to supplement the literature search. Google scholar was tested; the results were less focused including MSc thesis of unknown quality ranking above the key papers in the field. It was not felt that Google Scholar added anything to the academic literature review.

The search criteria and terms used with the on-line databases to identify relevant articles were structured in terms of:

- Policy Measures/Levers e.g. taxation, regulation, incentives
- Areas of Application (namely, the modes of transport)
- Policy Outcomes

[8] http://www.civilservice.gov.uk/networks/gsr/resources-and-guidance/rapid-evidence-assessment/what-is
[9] https://luft.umweltbundesamt.at/measures/

Table 10 Search Terms

Policy Measures	Areas of Application	Policy Outcomes	Inclusion/Exclusion criteria
Low Emissions Zones Vehicle Retrofit Vehicle Scrappage Pricing mechanisms: • General Taxation • Direct costs Alternative fuels: • Fuel Additives • Electric or hydrogen vehicles Vehicle emission tests Walking Cycling Traffic management Consolidation Centres Public transport Land use planning Vehicle anti idling Parking Fleet recognition schemes Eco Driving Restricted access zones NOx absorbing coatings Vegetation barriers	Cars Freight/HGV/LGV Buses Transport Cycling/walking	Vehicle purchase/replacement Road traffic flows/composition/speed Congestion Traffic displacement Pollutant emissions Behaviour change Air quality Road accidents Social inequality	UK or EU only 2000 onwards English language Providing quantitative evidence

In the first stage of screening, the titles and abstracts of the articles were reviewed against predefined inclusion/exclusion criteria. In the second stage, the full content of the screened articles was reviewed against the inclusion/exclusion criteria. The robustness of evidence in terms of data quality and degree of bias was also assessed. This included where monitoring and modelling was reported consideration of uncertainties and systematic bias; confounding factor consideration on the impact of the measure on air quality including meteorology, impact from other measures or economic conditions; the representativeness to the UK. The confidence in evidence given in the articles was ranked in terms of the methodological quality and relevance with particular attention to the potential for bias introduced by the study protocols. The type, amount, quality, and consistency of evidence, and the degree of agreement were also taken into account in determining the overall confidence ranking of the evidence. More specifically, in the first stage of screening, the titles and abstracts of the articles were reviewed against predefined inclusion/exclusion criteria.

The Endnote Star field was used to rank the papers according to relevance and content, Table 13 summarises the following star rating:

0. No apparent relevant information
1. New or relevant concept that may complement or support other papers

2. May be relevant includes numerical data which may be adaptable by developing a ranking or correlating factor, e.g. behaviour response or relate PM change to NO_2 Relevant and implies numerical data
3. Highly relevant includes numeric data in abstract or implies numerical data

Table 11 Number of articles after Stage 1 of the Science Direct screening process

Policy Measures	Total number of articles
Low Emissions Zone (LEZ)	28
Vehicle Retrofit	41
Vehicle Scrappage	18
Pricing Mechanism	
• Direct Costs	145
• General Taxation	34

A full list of reference used in the Rapid Evidence Review is given in Section 7.

The review

The articles and reports that form the basis of the evidence review were analysed to determine what was indicated in relation to the questions given in Table 12, the implications of the findings on the proposed policy measures and suggestions for further research based on evidence gaps and uncertainties.

Table 12 Questions for the detailed review

Specific Questions
Primary research question:
What quantifiable effect might a range of policy measures potentially have on NO_2 concentrations?
Secondary research questions:
What quantifiable effect might the specified policies have on perceptions or behaviours amongst the general public, specific transport user groups or other stakeholders?
What quantifiable effect might the specified policies have on traffic flows, composition and speed?
What quantifiable effect might the specified policies have on NO_X emissions?
What are the unintended consequences, including effects on other pollutants and other environmental/ social effects? Are there any disproportionate impacts on particular groups of people/organisations?
What are the contributory factors (triggers and barriers) to effective implementation of a package of measures to reduce NO_2 concentrations at both a local and national level?

Record of literature reviewed

4. For each publication that has been reviewed, summaries of the findings and details of the publication (e.g. title and abstract, the reference, etc.) were recorded in the Endnote reference management software. An endnote style was adapted to record the questions for the detailed review in Table 12 separately.

Table 13 summarises the volume and characteristics of the overall evidence base after the papers have been reviewed (Stage 2), this includes grey literature.

Table 13 Ranking of articles after Stage 2 of the screening process

Policy Measures	Ranking of Evidence Robustness			Total number of articles
	High 5*	Medium 4* - 3*	Low 2* - 1*	
Low Emissions Zone (LEZ)	18	13	9	40
Vehicle Retrofit	1	13	19	33
Vehicle Scrappage	0	12	12	24
Pricing Mechanism				
• Direct Costs	2	40	15	57
• General Taxation	5	14	21	40
Alternate Fuel	12	57	24	93
Cycling	1	8	7	16

Science Direct Search Terms

Fields searched: Abstract, title and keywords

Publication year: 2000-present

Sciences categories: All categories, none excluded

Table 14 Science Direct Search Categories

Physical Sciences and Engineering	Life Sciences	Health Sciences	Social Sciences and Humanities
Chemical Engineering	Agricultural and Biological Sciences	Medicine and Dentistry	Arts and Humanities
Chemistry	Biochemistry, Genetics and Molecular Biology	Nursing and Health Professions	Business, Management and Accounting
Computer Science	Environmental Science	Pharmacology, Toxicology and Pharmaceutical Science	Decision Sciences
Earth and Planetary Sciences	Immunology and Microbiology	Veterinary Science and Veterinary Medicine	Economics, Econometrics and Finance
Energy	Neuroscience		Psychology
Engineering			Social Sciences
Materials Science			
Mathematics			
Physics and Astronomy			

<u>Primary measures search terms:</u>

Low Emissions Zones

Policy Measures	And Area of Application	And Policy Outcome	Number of Articles
({Low emission zone} OR {Low emission scheme} OR {Bus priority} OR {High occupancy vehicle lane} OR {Motorway speed limit} OR {Anti-idling} OR {Idling ban} OR {Low emission vehicle lane} OR {Lorry ban} OR {Restricted access zone})	(Vehicle* OR Car* OR Petrol OR Diesel OR Bus* OR {Light good*} OR {Heavy good*} OR Van* OR Lorry*)	({Vehicle purchase} OR {Vehicle sale*} OR Journey* OR Traffic OR Emission* OR {Air pollution} OR Pollution)	
x			**37**
x	x		35
x		x	28
x	x	x	**27**
Select Statement **TITLE-ABSTR-KEY** (({Low emission zone} OR {Low emission scheme} OR {Bus priority} OR {High occupancy vehicle lane} OR {Motorway speed limit} OR {Anti-idling} OR {Idling ban} OR {Low emission vehicle lane} OR {Lorry ban} OR {Restricted access zone}) **AND** ({Vehicle purchase} OR {Vehicle sale*} OR Journey* OR Traffic OR Emission* OR {Air pollution} OR Pollution))			28

Vehicle Retrofit

The Application and Outcome search filters used for the LEZ search did not reduce the retrofit measures to a manageable number of papers. Taking into account the objective was to identify papers including quantitative values to be used for modelling air quality benefits. The additional search terms were focused on studies of fleet transport or including details related to NO2.

Policy Measures	And Area of Application	And Policy Outcome	Number of Articles
({Retrofit engine} OR {Retrofit abatement} OR {Retrofit catalyst} OR Re-engine OR {Engine replacement})	fleet	NO2	
x			335
x	x		27
x		x	16
x	and	and	2
x	**and**	**or**	**41**
Select Statement			
TITLE-ABSTR-KEY (({Retrofit engine} OR {Retrofit abatement} OR {Retrofit catalyst} OR Re-engine OR {Engine replacement}) **AND** ({no2} or {fleet}))			41

Vehicle Scrappage

Policy Measures	And Area of Application	And Policy Outcome	Number of Articles
(Scrappage OR {Replacement grant*} OR {Replacement incentive})	(Vehicle* OR Car* OR Petrol OR Diesel OR Bus* OR {Light good*} OR {Heavy good*} OR Van* OR Lorry*)	({Vehicle purchase} OR {Vehicle sale*} OR Journey* OR Traffic OR Emission* OR {Air pollution} OR Pollution)	
x			22
x	**x**		**18**
x		x	16
x	x	x	16
Select Statement			
TITLE-ABSTR-KEY ((Scrappage OR {Replacement grant*} OR {Replacement incentive}) **AND** (Vehicle* OR Car* OR Petrol OR Diesel OR Bus* OR {Light good*} OR {Heavy good*} OR Van* OR Lorry*))			18

Pricing Mechanism

General Taxation (e.g. vehicle duty, vehicle tax, fuel tax)

Direct costs (e.g. grants, fiscal incentives, road pricing, private roads, etc.)

Policy Measures	And Area of Application	And Policy Outcome	Number of Articles
General Taxation			
Tax	({Vehicle Excise Duty}) OR ({Road tax} OR {Fuel tax} OR {Vehicle sales tax} OR {Low emission vehicle purchase grant} OR {Fiscal incentives for low emission vehicles} OR {Biofuel tax credit})	**AND** ({Vehicle purchase} OR {Vehicle sale*} OR Journey* OR Traffic OR Emission* OR {Air pollution} OR Pollution)	34
Direct Costs			
Public Transport	{Public transport subsidy} OR {Bus subsidy} OR {Car share subsidy}		2
Parking	({Workplace parking levy} OR {Workplace parking fee} OR {Parking fee})	**AND** ({Vehicle purchase} OR {Vehicle sale*} OR Journey* OR Traffic OR Emission* OR {Air pollution} OR Pollution)	11
Roads	({Road user charge} OR {Road toll}OR {Road pricing} OR {Congestion charge})	**AND** ({Vehicle purchase} OR {Vehicle sale*} OR Journey* OR Traffic OR Emission* OR {Air pollution} OR Pollution)	132 (53 ranked 1* or above)

<u>Second tier search terms:</u>

Fuel

- Alternative fuels (electric vehicles and hydrogen fuel)
- Diesel exhausts fluids e.g. Ad Blue - selective catalytic reduction fluids to reduce NOx in exhaust emissions

Alternative fuel - Electric vehicles (HEV PHEV) and Hydrogen fuel (FCV)

Measures	And Application	And Outcome	No. papers
({HEV} OR {PHEV} OR {FCV})	NO2 OR CO2 OR GHG	(Emission* OR {Air pollution} OR Pollution)	
x	x	x	84
		and Bus HGV LGV	13
Select Statement			
TITLE-ABSTR-KEY (({HEV} OR {PHEV} OR {FCV}) AND (Emission* OR {Air pollution} OR Pollution) AND (NO2 OR CO2 OR GHG))			84
TITLE-ABSTR-KEY (({HEV} OR {PHEV} OR {FCV}) AND (Emission* OR {Air pollution} OR Pollution) AND (NO2 OR CO2 OR GHG) AND (Bus* OR {Light good*} OR {Heavy good*} OR Van* OR Lorry*))			13

Diesel exhausts fluids (Ad Blue)

Policy Measures	And Area of Application	And Policy Outcome	Number of Articles
{Ad Blue} OR {SRC})*	NO2 OR CO2 OR GHG	(Emission* OR {Air pollution} OR Pollution)	
x	x	x	65
	({Vehicle } OR Journey* OR Traffic))	(Emission* OR {Air pollution} OR Pollution)	**41**
Select Statement			
TITLE-ABSTR-KEY (({Ad Blue} OR {SCR}) AND (Emission* OR {Air pollution} OR Pollution) AND ({Vehicle } OR Journey* OR Traffic))			41
• SRC (Selective Catalytic Reduction) was the more appropriate select term than DEF (Diesel Exhaust Fluid)			

PubMed search

It was noted that the science direct searches omitted known papers published in medical journals. A general search was done using PubMed to search for any measures reporting cost/benefit information related to air pollution and traffic. This added 17 papers to the search, mostly considered moderately interesting. The most important papers had already been identified.