Exploring and appraising proposed measures to tackle air quality

Project summary report for contract AQ0959

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Executive summary

Context, aims and scope of the project

There is clear evidence that there is a causal relationship between exposure to air pollution and health impacts. 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)[1].

This project, conducted by Ricardo Energy & Environment on behalf of Defra, produced analysis and tools to inform the development of the 2015 UK National Air Quality Plan for NO_2 and future policy. The project reviewed evidence of the effectiveness of road transport policy measures to improve air quality (with a focus on nitrogen dioxide, NO_2), and developed tools – informed by the evidence gathered – to assist in the selection of measures and to estimate the future effects of such measures on air quality.

Due to the strong link between emissions from road transport and poor air quality, this work assessed measures addressing emissions from this sector alone. It is recognised however that sectors other than road transport can also contribute to poor air quality, such as residential fuel combustion and industrial sources. Although this study has focussed on NO_2 concentrations, many measures targeting NO_x emissions may be expected to deliver air quality benefits across a range of pollutants.

Activities carried out to meet the project aims

Three main steps were undertaken:

1. Literature review on the effectiveness of specific road transport measures to improve air quality.
2. In the absence of sufficient data on the effectiveness of measures (from step 1), a series of 'response functions' were developed that estimate how the use of vehicles (i.e. kilometres driven, composition of the fleet) may vary if the upfront or running costs of vehicles changed. These functions were developed from evidence identified in a further literature review and an expert elicitation exercise. A response function may represent multiple possible policy measures to improve air quality.
3. A 'streamlined PCM' tool was developed that enables the user to rapidly estimate NO_X and NO_2 emission and concentration impacts of changes in fleet composition and distance travelled by vehicles. The tool is a simplified version of Defra's Pollution and Climate Mapping (PCM) model. A 'Translation Tool' was also developed, to model the estimated effects of changes in upfront or running costs of vehicles on vehicle fleet composition and distance travelled, based on the response functions developed in step 2. These two tools are linked, to estimate impacts on NO_X and NO_2 of changes in costs to vehicles.

Findings on the effectiveness of specific road transport measures to improve air quality

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 diesel vehicles, 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. 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.

The following more specific measures appeared to have the most potential to be effective:

[1] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/486636/aq-plan-2015-overview-document.pdf

Traffic management and access control measures can be very effective as they directly reduce or remove the source of the air pollution problem. However, they can be expensive to implement and politically unpopular if not handled sensitively or placed within wider area redevelopment.

Promoting low emission vehicles and technologies can generate significant emission and air quality benefits if taken up substantially and can provide wider economic benefits through developing, producing and servicing new vehicle technologies. However, they are not always as effective as expected due to low uptake, can be costly, and do not provide local benefits such as reduced congestion or increased levels of physical activity.

Demand management measures and measures that encourage people to shift to lower emission transport modes can be very cost effective and can have a wide range of benefits including reduced congestion, improved air quality, reduced carbon emissions and increase levels of physical activity. The evidence base linking such measures directly to air quality benefits is not always clear however. Travel attitudes and habits are often deep rooted and hard to change, so such measures need to be combined with ongoing travel option information provision.

The use of *pricing mechanisms* to influence the purchase choice of vehicles and their use is considered a very cost effective measure as they use 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 with 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 categories of measures are not mutually exclusive: studies show that transport interventions are often combined in the aim of achieving a greater impact. Most measures on their own may only generate a small reduction in road vehicle emissions. 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.

The review of effectiveness of measures to improve air quality yielded limited quantitative information. 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.

Findings on behavioural responses to changes in vehicle economics and modelling air quality impacts

As the evidence review yielded limited quantitative information on the effectiveness of measures to improve air quality, an alternative approach was taken to estimate the air quality impacts of measures. The alternative approach considered that policy measures for reducing the air quality impacts of road transport could be categorised into:

- measures which affect upfront costs of vehicles,
- measures which change running costs of vehicles, and
- measures which only affect running costs of vehicles within geographically restricted zones

These generic categories of costs hence may each represent one or more possible policy measures.

Based on evidence in literature and through an expert elicitation exercise, 'response functions' have been estimated for 20 such generic measures (Table ES1). The functions quantify, for a given cost change, how road traffic may be impacted in 2020 in terms of vehicle flows (kilometres driven), the mix of each vehicle category (fleet composition) and shifts between modes (e.g. from private to public transport).[2]

Tools to estimate air quality impacts of measures

A simplified road traffic emissions model was needed to enable rapid estimation of NO_X emission and roadside NO_2 concentration impacts of measures. To meet this need, the 'Streamlined PCM' tool was developed, based on Defra's Pollution Climate Mapping (PCM) model. The Streamlined PCM tool estimates projections for road transport NO_X emissions and roadside NO_2 concentrations by modelling the effect of changes in road traffic (in terms of vehicle numbers, location, speed and distance travelled) on major roads and motorways across the UK. Further information on the Streamlined PCM tool, including a detailed description of the sources of data used and the modelling assumptions made is available in its technical report.[3]

However, it can be challenging when appraising a road transport measure to characterise the degree of variation of road traffic between the policy scenario under appraisal and a baseline. Therefore, the response functions characterising behaviour responses to vehicle cost changes (described above) and a further tool to incorporate these was developed. This second tool, a 'Translation Tool', when coupled with the Streamlined PCM tool, can rapidly estimate NO_X emission and NO_2 concentration impacts of road transport policy measures that are specified in terms of changes in vehicle costs. This simplifies the user inputs needed to appraise potential road transport policy options. The Translation Tool provides the ability to apply and assess impacts of measures at multiple geographic scales – whether by region, local authority, defined urban area or for individual major roads.

There are a range of limitations associated with this approach, with the main implications being that the results estimated in the Translation Tool are to be interpreted as indicative only due to a limited evidence base, and that more detailed analysis should be carried out on potential policy options to be taken further. One measure may not necessarily lead to the same air quality impact in one location as it does in another location. In particular, primary research and dynamic modelling (for example using DfT models) could be carried out to increase confidence in estimated impacts, although such models would need further development and investment before being used for this means. The evidence base was stronger for estimating the impacts of changing running costs of cars, but weaker for estimating effects of most other cost changes (other vehicle types and other cost types). In the recognition of the uncertainty in behavioural responses, each function has been described in terms of a central estimate and a low and a high estimate. Other input variables are available to be selected in the Translation Tool user interface to form upper and lower bounds for possible emission impacts of response functions. Other limitations and their implications have been described in Section 3.6 of this report.

Given the number of functions and possible variables for each function, and that the focus of this analysis was to deliver a Tool for Defra that enables assessment of how changes in vehicle costs could affect air quality, the *full* estimated NO_X and NO_2 impacts of each response function are not presented in this report. However, Table ES1 does include example NO_X impacts for each response function based on a specific change in cost (and presented as a single central estimate only). Detailed results from one function are presented in the main body of this report, and full details on all the response functions are available in Appendix 2.

[2] The model used by Defra to project future nitrogen dioxide concentrations was set up to look at five-year intervals going forward, hence the use of the year 2020 for the response function exercise.

[3] http://uk-air.defra.gov.uk/assets/documents/reports/cat09/1511260938_AQ0959_Streamlined_PCM_Technical_Report_(Nov_2015).pdf

Table ES1: 20 response functions were developed across four vehicle categories, with impacts on fleet composition, distances travelled and modal shift estimated

Vehicle category	Cost variable	Response functions developed	Validity range*	Impacts estimated			Central result		Notes
				Fleet composition	Kilometres driven	Modal shift	Cost change	Total NO_x emission impact**	
Cars	Upfront costs	1: Decrease upfront costs of PHEVs and BEVs	-20% to 0	✓			-10%	-0.3%	1,2
		3: Increase upfront costs of petrol/diesel cars	0 to +20%	✓	✓		+10%	-0.3%	1,2,4
	Running costs	12: Change running costs of cars	-50 to +50%		✓	bus	+10%	-1.7%	1,2
		6: Increase running costs of petrol/diesel cars	0 to +39%	✓	✓		+10%	-1.2%	1,2,4
	Running costs in restricted zone	13. Change running costs of all cars in restricted zones (congestion charge)	0 to +115%		✓		+50%	-1.9%	1,3
		7. Increase running costs of petrol/diesel cars in restricted zones (congestion charge)	0 to +115%	✓	✓		+50%	-0.5%	1,3,4
		4. Increase running costs of petrol/diesel cars in restricted zones (LEZ) (Euro 4 petrol, Euro 6 diesel)	0 to £100/day	✓	✓	bus	+50%	-4.8%	1,3
		5. Increase running costs of petrol/diesel cars in restricted zones (LEZ) (zero emission capable)	0 to £100/day	✓	✓	bus	+50%	-6.7%	1,3
LGVs	Upfront costs	2. Decrease upfront costs of PHEV/BEV LGVs	-20% to 0	✓			-10%	-0.2%	1,2
		11. Change LGV upfront costs	-20 to +20%		✓		+10%	-0.2%	1,2
	Running costs	10. Change LGV running costs	-50 to +50%		✓		+10%	-0.4%	1,2
		14. Increase running costs of diesel LGVs	0 to +20%	✓			+10%	-0.1%	1,2,4
	Running costs in restricted zone	15. Increase running costs of diesel LGV in restricted zones (LEZ) (Euro 6 diesel)	0 to £100/day	✓	✓	bus	+£10	-1.1%	1,3
		16. Increase running costs of diesel LGV in restricted zones (LEZ) (zero emission capable)	0 to £100/day	✓	✓	bus	+£10	-0.6%	1,3

Vehicle category	Cost variable	Response functions developed	Validity range*	Impacts estimated			Central result		Notes
				Fleet composition	Kilometres driven	Modal shift	Cost change	Total NO_X emission impact**	
HGVs	Upfront costs	18. Change upfront costs of HGVs	-20 to +20%		✓	rail	+10%	-0.01%	1,2,4
	Running costs	9: Change running costs of HGVs	-26 to +26%		✓	rail	+10%	-0.5%	1,2
	Running costs in restricted zone	20. Increase running costs of HGVs in restricted zones (LEZ)	0 to £100/day	✓	✓	rail	+£50	-0.1%	1,3,4
Buses and coaches	Upfront costs	8: Change upfront costs of buses	-20 to +20%		✓	car, rail	+10%	+0.01%	1,2,4
	Running costs	19: Change running costs of buses	-50 to +50%		✓	car, rail	+10%	-0.6%	1,2
	Running costs in restricted zone	17. Increase running costs of buses in restricted zones (LEZ)	0 to £100/day	✓	✓		+£50	-0.1%	1,3

** Validity range expressed in % change in daily costs, except for response functions for running costs in restricted zones when expressed as £/day (principally to reflect for LGVs and HGVs that a percentage of costs for different LGV and HGV categories would otherwise translate into different absolute costs.*

*** Total for the UK as included in the scope of the Streamlined PCM tool, i.e. tailpipe emissions from road transport on the 18,346 major roads in the tool.*

Table notes:

1) *UK total NOx emission impact is the percentage reduction from total NOx emissions from road vehicles on all the roads assessed in the Streamlined PCM tool, which total 47.7kt NOx across the UK. In all response functions the central estimate is presented. High and low uncertainty bounds for the emission impact are not shown. Central estimate assumes (where relevant) a 50:50 split between PHEVs and BEVs, and a 50:50 split between LGVs being owner-driven and fleet-driven.*
2) *For response functions for upfront or running costs: Result assuming the measure is applied nationally (all regions, all local authorities).*
3) *For response functions for running costs in restricted zones: Result assuming the measure is applied to defined restricted zones in various UK cities that were able to be modelled using the Streamlined PCM tool.*
4) *Result assuming the measure is assumed to begin implementation in year 2018. Larger impacts would be expected to occur for earlier start dates; smaller impacts would be expected to occur for later start dates.*

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Appendices

Appendix 1 Evidence review on effectiveness of transport measures in reducing nitrogen dioxide

Appendix 2 Evidence review and expert elicitation exercise on behavioural responses to changes in vehicle economics

Glossary

AQD	Ambient Air Quality Directive 2008/50/EC
BEV	Battery electric vehicle
GHG	Greenhouse gas
HGV	Heavy goods vehicle
LEZ	Low emission zone
LGV	Light goods vehicle
NAEI	National Atmospheric Emissions Inventory
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_X	Nitrogen oxides
PCM model	Pollution Climate Mapping model
PHEV	Plugin hybrid electric vehicle
$PM_{2.5}$	Fine particulate matter (with diameter 2.5 microns or smaller)

1 Introduction

1.1 Context of the work

There is a clear link between NO_2 exposure and health

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[4]. 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)[5].

Air quality is poor near busy roads

Internal combustion engines emit both nitric oxide (NO) and NO_2 – together referred to as nitrogen oxides (NO_X). Some of the NO reacts in the atmosphere to form NO_2. However, the NO_2 directly emitted from vehicles (primary NO_2) makes a substantial contribution to concentrations of NO_2 measured at the roadside. Current (latest Euro standard) diesel cars and vans emit a relatively large proportion of NO_X as primary NO_2 compared to current petrol cars and heavy duty vehicles.

Poor air quality and high concentrations of NO_2 can be in many cases largely attributed to NO_X and NO_2 emissions from road vehicles.[6] Hence, the largest improvements to air quality and greatest reductions needed to comply with the limit values are at locations close to heavily trafficked roads. Sectors other than road transport however can also contribute to poor air quality, such as residential fuel combustion and industrial sources.

In the past, the introduction of more stringent Euro standards has not always produced the expected reduction in real world NO_X emissions.

Policies are in place to limit NO_2 exposure which benefits human health

The Air Quality Directive (AQD) sets limits for a number of pollutants, taking into account guidelines from the World Health Organisation. The AQD limit values for NO_2 are:

- 200 µg m^{-3} as an hourly mean, not to be exceeded more than 18 times in a calendar year, and
- 40 µg m^{-3} as an annual mean.

The AQD required EU Member States to achieve these limit values from 1 January 2010. Member States could postpone this deadline by a maximum of five years on condition that an air quality plan was established for each non-compliant zone or agglomeration demonstrating that compliance would be achieved by 1 January 2015. In September 2011, Defra and the devolved administrations published updated air quality plans for the achievement of the NO_2 limits in the UK, which listed existing and planned measures to tackle the issue, and obtained a postponement to 1 January 2015 for compliance in 12 zones. In 2014 the European Commission commenced infringement proceedings against the UK for failure to meet the NO_2 limit values by 1 January 2010 in zones for which no postponement was granted. Defra committed to producing revised air quality plans by the end of 2015 to demonstrate commitment to complying with the NO_2 limit values in the shortest possible time. This timeline was incorporated into a Supreme Court Order following a judicial review challenge in the UK courts.

In December 2015, the Government published a new National Air Quality Plan including national measures to help achieve compliance with the NO_2 limit values, alongside revised individual plans for each non-compliant zone.[7]

The UK is divided into 43 zones and agglomerations for the purpose of air quality assessment under the AQD. Annual mean NO_2 concentrations for 2013 exceeded the annual mean limit value at some

[4] https://www.gov.uk/government/publications/nitrogen-dioxide-health-effects-of-exposure
[5] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/486636/aq-plan-2015-overview-document.pdf
[6] For example, section 2 of https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/82273/draft-overview-doc.pdf
[7] https://www.gov.uk/government/publications/air-quality-in-the-uk-plan-to-reduce-nitrogen-dioxide-emissions

locations within 38 of the 43 zones (seven of these zones were within margins of tolerance). Measured concentrations in 2013 exceeded the hourly limit value at some locations in one zone, that of Greater London. The latest projections for NO_2 compliance[7] estimates that, accounting for existing and additional measures outlined in the new UK Air Quality Plan, compliance with the limit values is expected to be achieved in 37 of the exceeding zones by 2020 (with the exception of Greater London), and in London by 2025.

Seventeen other European countries have also requested under Article 22 of the AQD additional time to reduce NO_2 levels to comply with the annual NO_2 limit value. Many of these also do not comply with the limit values for coarse PM (PM_{10}). Across Europe the challenge is to identify and implement a range of policy measures at a national and local level that can be reasonably implemented to reduce NO_2 concentrations to benefit human health and meet the limit values set by the AQD.

As well as targets for air quality, the UK has targets set under the framework of the UNECE Gothenburg Protocol and the EU's National Emission Ceiling Directive for total NO_X emissions. Whilst the UK met its 2010 target, potential future ceilings may still be challenging to meet. Road transport continues to be a major contributor to total NO_X emissions in the UK, and so reductions in this sector will assist meeting future national NO_X ceilings.

Measures to reduce NO_2 concentrations must not jeopardise other Government objectives, including carbon commitments

Measures to improve air quality need to be consistent with other Government objectives supporting economic growth, improving accessibility, and reducing Greenhouse Gases (GHGs). GHG emissions from road transport make up 19% of the UK's total GHG emissions.[8] Meeting the future UK carbon budgets set under the Climate Change Act – in particular the fourth carbon budget – will require GHG emission reductions from the road transport sector[9]. Any measures to reduce NO_X emissions and NO_2 concentrations from road transport would aim to avoid increasing GHG emissions, and ideally reduce them.

1.2 Aims and objectives of this project

This project, conducted by Ricardo Energy & Environment on behalf of Defra, produced analysis and tools to inform the development of the 2015 UK National Air Quality Plan for NO_2 and future policy. Due to the strong link between emissions from road transport and poor air quality, this work assessed measures addressing emissions from this sector alone.

The project 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 study has produced tools to assess impacts on air quality in terms of changes in NO_2 concentrations at selected roadside locations.

Although this study has focussed on NO_2 concentrations, many measures targeting NO_2 emissions may be expected to deliver air quality benefits across a range of pollutants. The impacts on other pollutants and other secondary impacts and unintended consequences are also noted where described in the published literature.

The research questions are set out in Box 1.

[8] https://www.gov.uk/government/statistics/final-uk-emissions-estimates
[9] https://www.theccc.org.uk/wp-content/uploads/2014/07/1911_CCC_PR2014_ES.pdf

Box 1 – Research 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 Methodology

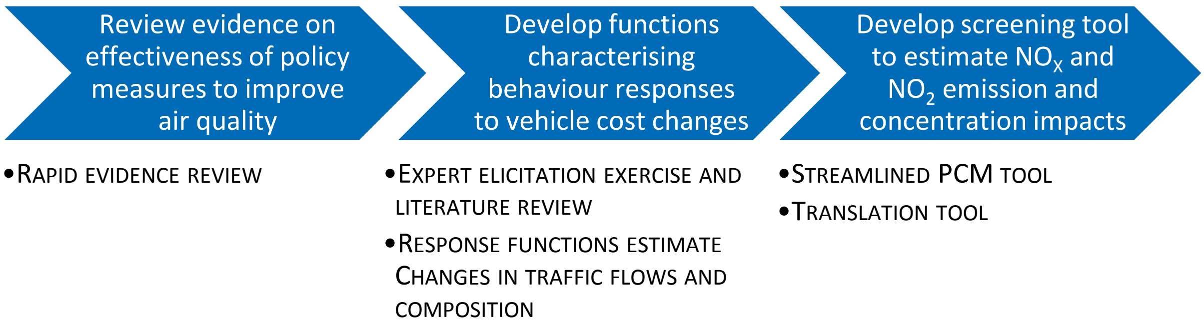
2.1 Summary of methodology

The main steps undertaken to try to answer the research questions outlined in section 1.2 were:

1. A review of evidence on the effectiveness of road transport measures to improve air quality was carried out.
2. In the absence of sufficient data on the effectiveness of existing measures (step 1), a series of 'response functions' were developed that estimate how the use of vehicles (i.e. kilometres driven, composition of the fleet) may vary if the upfront or running costs of vehicles changed. These functions were developed from evidence identified in a further literature review and an expert elicitation exercise. A response function may represent multiple possible policy measures to improve air quality.
3. A simplified version of Defra's Pollution and Climate Mapping (PCM) model, the 'streamlined PCM' tool, was developed that enables the user to rapidly estimate NO_X and NO_2 emission and concentration impacts of changes in fleet composition and distance travelled by vehicles. A 'Translation Tool' was also developed, to model the estimated effects of changes in upfront or running costs of vehicles on vehicle fleet composition and distance travelled, based on the response functions developed in step 2. These two tools are linked, to estimate impacts on NO_X and NO_2 of changes in costs to vehicles.

These steps are summarised in Figure 1 and elaborated in the following subsections. Limitations associated with the methodology are summarised in section 3.6, in particular in Table 4 and Table 5.

Figure 1 – Overview of the main steps in this study methodology



2.2 Review evidence on the effectiveness of road transport measures to improve air quality

An extensive review of over 400 published papers and reports was conducted to identify evidence from around the world on the effectiveness of measures to improve air quality and to identify key gaps in analysis. This review focused on measures to reduce NO_X emissions from road transport as this sector is the largest contributor to annual mean NO_2 limit value exceedances.[10] The literature review assigned measures into four categories:

- Measures that reduce emissions from existing vehicles;
- Measures that reduce demand for more polluting forms of transport;
- Measures that promote uptake and/or use of cleaner vehicles; and
- Measures that displace pollutant emissions outside hot spots and populated areas.

[10] For example, section 2.1 of Improving Air Quality in the UK, UK overview document December 2015 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/486636/aq-plan-2015-overview-document.pdf

It is important to note that this evidence review was limited to measures whose effectiveness has been studied in a robust way and where findings have been published in English. The effectiveness of the measures studied will also depend on the situational / geographic context, and the way in which they have been designed and implemented. This review was therefore intended to provide insight on the potential effectiveness of measures; where particular measures studied appear to be ineffective, this does not necessarily mean that they *cannot* have the desired impact, if designed appropriately.

The full evidence review methodology is included in Appendix 1, including search criteria and terms.

2.3 Develop functions characterising behaviour responses to vehicle cost changes

As the evidence review described in section 2.2 yielded limited robust quantitative information on the effectiveness of measures to improve air quality, an alternative approach was taken to estimate the air quality impacts of measures.[11] The second stage of the work considered that policy measures for reducing the air quality impacts of road transport could be categorised into:

- measures which affect upfront costs of vehicles,
- measures which change running costs of vehicles, and
- measures which only affect running costs of vehicles within geographically restricted zones[12]

These generic categories of costs hence may each represent one or more possible policy measures.[13] This approach is useful to allow a wide range of road transport measures to be considered, but is naturally limited to those that affect costs to users; non-monetary measures such as improved infrastructure for bicycles, or campaigns to encourage walking to work are not covered. People and businesses will react differently to different measures that fall into the same category; the nature of different measures should therefore be taken into consideration alongside use of the response functions.

The first step of this second stage was an exercise to estimate the likely behaviour changes of road transport users to changes to upfront and running costs of vehicles. The estimated changes in fleet composition and distance travelled as a function of cost changes are referred to as 'response functions'. This step was based on an expert elicitation exercise. This exercise selected a panel of experts to identify and quantify response functions and highlight evidence to support the response functions. Experts were selected for the panel based on:

(1) ensuring a range of suitable expertise – one or two specialists in each of the following topics were sought: transport behaviour change, transport economics, sustainable transport strategy, urban air pollution, bus fleets and low emission zones, road freight transport;

(2) ensuring a range of institutions were represented; and

(3) experts' availability to contribute during the period in which the elicitation exercise was conducted. Experts were supplemented with specialists from Ricardo Energy & Environment.

The suggestions of the expert panel on response functions was complemented by a further literature review focussed on elasticities. Drawing on the expert elicitation exercise and on the additional literature review, a proposed set of 20 response functions were developed by Ricardo Energy & Environment, covering cars, light goods vehicles (LGVs), heavy goods vehicles (HGVs) and buses & coaches. The proposed response functions and supporting analysis were peer reviewed and approved by selected members of the expert panel.

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[11] It was initially expected that the first evidence review (outlined in section 2.2) would have been followed by quantification of the impacts of different measures identified on a range of outcomes to input into the existing PCM model. Key gaps in the evidence base would have then been filled using primary research. However, the rapid review did not identify sufficient quantifiable evidence and an alternative second stage was planned and carried out, replacing the primary research.

[12] This categorisation has been made for the purpose of simplifying Defra's consideration of a wider number of possible policy measures; more detailed assessment of impacts of specific policy measures can then be carried out subsequently.

[13] For example, geographically-restricted measures could include a charge for entering a zone, or a change in parking charge in a particular zone.

2.4 Develop tools to estimate NO_X and NO_2 emission and concentration impacts of measures

A modelling framework was required to enable rapid assessment of the air quality impacts of possible road transport measures to improve air quality. A simplified road-traffic modelling tool, the Streamlined PCM tool, was developed based on Defra's Pollution Climate Mapping (PCM) model (see Box 2). The Streamlined PCM tool can rapidly assess NO_X emission and NO_2 concentration impacts of road transport policy measures when those policy measures are specified in terms of estimated changes in distances vehicles are driven and changes in the vehicle fleet.

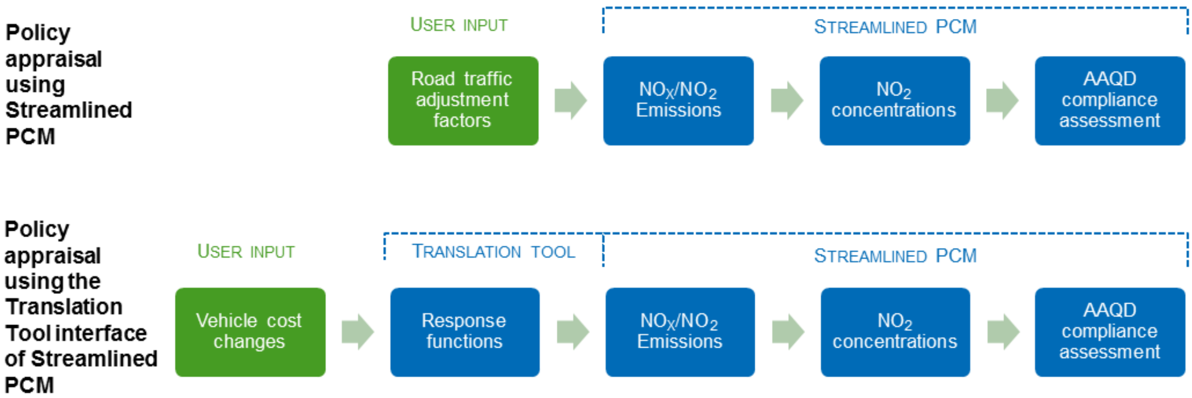
Box 2: The PCM model

The Pollution Climate Mapping (PCM) model is a UK national model that brings together information from ambient measurements, emission inventories and other models in a geographic information system environment to estimate current and future pollutant concentrations. The PCM model is used by Defra for AQD compliance reporting purposes, assessing against target values / limit values, as well as being used in a policy development context to assess the emission and concentration impacts of policy options.

However, it can be challenging when appraising a road transport measure to characterise the degree of variation of road traffic between the policy scenario under appraisal and a baseline. Therefore, the response functions characterising behaviour responses to vehicle cost changes (described in Section 2.3) and a further tool to incorporate these were developed. This second tool, a 'Translation Tool', when coupled with the Streamlined PCM tool, can rapidly estimate NO_X emission and NO_2 concentration impacts of road transport policy measures that are specified in terms of changes in vehicle costs. This simplifies the user inputs needed to appraise potential road transport policy options.

The two policy modelling options are compared in Figure 2. These two tools form an output of this study, and are described in more detail in Section 3.3.

Figure 2 The Translation Tool interface to the Streamlined PCM tool has simpler inputs than appraising policy scenarios using only the Streamlined PCM



3 Findings and outputs

3.1 Overview

This section describes the findings from the two main stages of this work.

Section 3.2 summarises the findings from the first step evidence review on the effectiveness of measures to improve air quality.

The findings from the second stage of the work on the development of response functions to generic cost measures and the development of tools to assess their impacts on NO_X and NO_2 emissions and concentrations are summarised in Sections 3.3 to 3.6 as follows:

- Section 3.3 summarises the tools that have been developed to estimate NO_X and NO_2 emissions and concentrations impacts of possible policy measures;
- Section 3.4 summarises the findings on estimating behavioural responses and resultant changes in the fleet to changes in vehicle economics;
- Section 3.5 provides, for one response function, much greater detail on the basis, assumptions, limitations and results; and
- Section 3.6 summarises the overall limitations of the evidence base, the approach to developing response functions and the emission and concentration modelling.

3.2 Findings on effectiveness of measures to improve air quality

This section summarises the key findings on which measures appear to have most potential to lead to the largest improvement in air quality, based on the evidence identified. Over 400 academic papers were reviewed for the impact of 72 policy measures to improve air quality; these are listed in Appendix 1. 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 full findings of the rapid evidence review are in Appendix 1.

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

- accelerating the up-take 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. 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.

The following more specific measures appeared to have the most potential to be effective:

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, 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.

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 price premia limiting take-up, 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. 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 ecodriving 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.

The use of pricing mechanisms to influence the purchase choice of vehicles and their use is considered a very cost effective measure as they use 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 with 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, 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. 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.

The full report on the evidence review is Appendix 1, including a reference list.

3.3 Tools for estimating NO_X and NO_2 impacts of road transport measures

As described in section 2.4, two tools were developed which can be combined to estimate the NO_X and NO_2 outcomes of changes in upfront and running costs of vehicles.

The Streamlined PCM tool

The Streamlined PCM tool was developed for Defra to rapidly assess NO_X emissions and NO_2 concentration impacts of road transport measures. The Streamlined PCM tool estimates projections for road transport NO_X emissions and roadside NO_2 concentrations by modelling the effect of changes in road traffic (in terms of vehicle numbers, location, speed and distance travelled) on major roads and motorways across the United Kingdom. The tool consists of two parts. One is a simplified road traffic emissions model that receives user input characterising the change in road traffic and estimates NO_X emissions from multiplying average vehicle flows and emission factors. The second is a parametrisation of the PCM model to estimate roadside NO_2 concentrations as a result of the changes in NO_X emissions.

The input data that are used by the Streamlined PCM tool consist of:

- **Emission factor variables**, which include: individual emission factors for different vehicles by type, fuel and Euro standard; the coefficients for speed-dependent functions to adjust emissions based on vehicle speed; and factors for primary NO_2 emissions for different vehicle and fuel types.
- **Composition variables**, including ratios of Euro standards for different vehicle and fuel types along with information on the total number of vehicle-kilometres by vehicle and road type. The Streamlined PCM tool considers several vehicle types (passenger cars, LGVs, urban buses, coaches, articulated and rigid HGVs, motorcycles and mopeds).
- **Activity variables**, which refer to annual average daily flows (i.e. traffic count) by vehicle type for the 18,346 major (motorway and A road) road links in the United Kingdom. Information on the different characteristics of each of the roads in the model is also available.
- **Concentration variables,** which correspond to the different concentration values considered by the full PCM model and that enable the estimation of the annual mean concentration of NO_2 at those receptors considered as urban major roads.
- **Geography variables**, which categorise the 18,346 road links in terms of their location within 406 local authorities, 20 of the larger urban centres and 12 regions (the 9 regions in England, with the other regions being Scotland, Wales and Northern Ireland).

Further information on the Streamlined PCM tool, including a detailed description of the sources of data and the modelling assumptions is available in its published technical report[14].

Translation Tool

An additional interface to the Streamlined PCM tool was developed in order to model (or ‘translate’) how changes in the three types of vehicle costs described in section 2.3 may impact on fleet composition and distance travelled. This interface is known as the ‘Translation Tool’, and it can be linked with the Streamlined PCM tool, to estimate changes in annual NO_2 concentrations for each of the response functions described in the next section (3.4).

The Translation Tool takes the response functions directly as inputs for changes in road traffic parameters (fleet composition and vehicle kilometres) and outputs estimated changes to emissions for each major road in the UK. The Translation Tool has been designed to allow users to select a single response function and for this function the user specifies the following input parameters:

- the scale of the change to upfront or running costs (within a validity range for each function);
- the geographic level to apply the measure to: national, local authority, defined geographic area or for individual roads;
- central estimate or low/high uncertainty bounds;
- the proportion of plugin vehicles that are plugin-hybrids rather than battery electric;
- (for response functions affecting LGVs) the estimated proportion of LGVs which are driven by their owners rather than fleet vehicles;
- (for some response functions) the year of application of the measure from 2016 to 2020.

[14] http://uk-air.defra.gov.uk/assets/documents/reports/cat09/1511260938_AQ0959_Streamlined_PCM_Technical_Report_(Nov_2015).pdf

In order to assess the additional detail of the response functions that were developed with respect to unconventional propulsion technologies, the Translation Tool covers more fuel types than the standard Streamlined PCM tool. The Translation Tool additionally considers petrol hybrid, diesel hybrid, plug-in hybrid electric and battery electric cars, which are not considered in the normal Streamlined PCM tool.

Apart from information on the resulting NO_X emissions and NO_2 concentrations, the Translation Tool provides the net change in vehicle kilometres for every vehicle type, fuel type and Euro standard produced by the selected lever. The tool also provides information on other impacts that do not directly affect the variables of the core emissions model, such as impact on passenger/freight railways (in tonnes or passenger kilometres). Additionally, to help understand response functions expressed as relative changes in vehicle costs, it also indicates the absolute cost change per vehicle.

3.4 Findings on behavioural responses to changes in vehicle economics

The findings presented in section 3.2 summarised the evidence on the potential effectiveness of specific measures to improve air quality (in particular to reduce NO_2) if designed appropriately. This section describes the outputs from the development of response functions which estimate behavioural responses to changes in vehicle costs.

This work identified sufficient evidence to develop 20 response functions which aim to capture estimated impacts in 2020 – at a national level or in restricted zones (based on average impacts) – in response to hypothetical changes to upfront or running costs of different vehicle types. The impacts are characterised in terms of:

- Changes in vehicle flows (kilometres driven);
- The mix of each vehicle category on the roads – i.e. fuel type and emission class (fleet composition);and
- Shifts between modes (e.g. from private to public transport).

Recognising the uncertainty associated with these behavioural responses, each function has been described in terms of a central estimate bounded by low and high uncertainty estimates.

Appendix 2 of this document summarises the evidence that was identified through the expert elicitation exercise and complementary literature review to inform these response functions. Appendix 2 also includes a description of each response function and a plot of its main outputs in terms of vehicle kilometres or fleet composition. Section 3.5 in this report provides as an example, further information on the evidence underpinning one response function and assumptions made, its applicability and limitations, and its results.

An overview of all 20 response functions generated is included in Table 1. This table shows for example that three response functions were estimated for HGVs: one estimates the impacts on HGV kilometres driven and modal shift to rail freight as a function of changing upfront costs of HGVs; a second estimates the impacts on HGV kilometres driven and modal shift to rail freight as a function of changing running costs of HGVs; and a third estimates the impacts on HGV fleet composition, HGV kilometres driven and modal shift to rail freight as a function of changing running costs of HGVs within restricted zones.

Given the number of functions, scenarios and variables, the full estimated NO_X and NO_2 impacts of each response function are not presented in this report; the Streamlined PCM tool can be used to estimate these impacts. However, Table 1 does include example NO_X impacts for each response function based on a specific change in cost (and presented as a single central estimate only).

As described in section 2.4, these response functions were built into a 'Translation Tool' to allow a user to estimate the possible range of impacts of a single response function, varying the degree of cost changes. If it is valid to apply multiple response functions together (see limitations section 3.6) the effects of multiple response functions can be estimated through the combination of the emission variation ratios produced under the individual response functions. This combination involves calculating the product across all the ratios for each road.

Table 1: 20 response functions were developed across four vehicle categories, with impacts on fleet composition, distances travelled and modal shift estimated

Vehicle category	Cost variable	Response functions developed	Validity range*	Impacts estimated			Central result		Notes
				Fleet composition	Kilometres driven	Modal shift	Cost change	Total NO_X emission impact**	
Cars	Upfront costs	1: Decrease upfront costs of PHEVs and BEVs	-20% to 0	✓			-10%	-0.3%	1,2
		3: Increase upfront costs of petrol/diesel cars	0 to +20%	✓	✓		+10%	-0.3%	1,2,4
	Running costs	12: Change running costs of cars	-50 to +50%		✓	bus	+10%	-1.7%	1,2
		6: Increase running costs of petrol/diesel cars	0 to +39%	✓	✓		+10%	-1.2%	1,2,4
	Running costs in restricted zone	13. Change running costs of all cars in restricted zones (congestion charge)	0 to +115%		✓		+50%	-1.9%	1,3
		7. Increase running costs of petrol/diesel cars in restricted zones (congestion charge)	0 to +115%	✓	✓		+50%	-0.5%	1,3,4
		4. Increase running costs of petrol/diesel cars in restricted zones (LEZ) (Euro 4 petrol, Euro 6 diesel)	0 to £100/day	✓	✓	bus	+50%	-4.8%	1,3
		5. Increase running costs of petrol/diesel cars in restricted zones (LEZ) (zero emission capable)	0 to £100/day	✓	✓	bus	+50%	-6.7%	1,3
LGVs	Upfront costs	2. Decrease upfront costs of PHEV/BEV LGVs	-20% to 0	✓			-10%	-0.2%	1,2
		11. Change LGV upfront costs	-20 to +20%		✓		+10%	-0.2%	1,2
	Running costs	10. Change LGV running costs	-50 to +50%		✓		+10%	-0.4%	1,2
		14. Increase running costs of diesel LGVs	0 to +20%	✓			+10%	-0.1%	1,2,4
	Running costs in restricted zone	15. Increase running costs of diesel LGV in restricted zones (LEZ) (Euro 6 diesel)	0 to £100/day	✓	✓	bus	+£10	-1.1%	1,3
		16. Increase running costs of diesel LGV in restricted zones (LEZ) (zero emission capable)	0 to £100/day	✓	✓	bus	+£10	-0.6%	1,3

Vehicle category	Cost variable	Response functions developed	Validity range*	Impacts estimated			Central result		Notes
				Fleet composition	Kilometres driven	Modal shift	Cost change	Total NO_X emission impact**	
HGVs	Upfront costs	18. Change upfront costs of HGVs	-20 to +20%		✓	rail	+10%	-0.01%	1,2,4
	Running costs	9: Change running costs of HGVs	-26 to +26%		✓	rail	+10%	-0.5%	1,2
	Running costs in restricted zone	20. Increase running costs of HGVs in restricted zones (LEZ)	0 to £100/day	✓	✓	rail	+£50	-0.1%	1,3,4
Buses and coaches	Upfront costs	8: Change upfront costs of buses	-20 to +20%		✓	car, rail	+10%	+0.01%	1,2,4
	Running costs	19: Change running costs of buses	-50 to +50%		✓	car, rail	+10%	-0.6%	1,2
	Running costs in restricted zone	17. Increase running costs of buses in restricted zones (LEZ)	0 to £100/day	✓	✓		+£50	-0.1%	1,3

** Validity range expressed in % change in daily costs, except for response functions for running costs in restricted zones when expressed as £/day (principally to reflect for LGVs and HGVs that a percentage of costs for different LGV and HGV categories would otherwise translate into different absolute costs.*

*** Total for the UK as included in the scope of the Streamlined PCM tool, i.e. tailpipe emissions from road transport on the 18,346 major roads in the tool.*

Table notes:

1) *UK total NOx emission impact is the percentage reduction from total NOx emissions from road vehicles on all the roads assessed in the Streamlined PCM tool, which total 47.7kt NOx across the UK. In all response functions the central estimate is presented. High and low uncertainty bounds for the emission impact are not shown. Central estimate assumes (where relevant) a 50:50 split between PHEVs and BEVs, and a 50:50 split between LGVs being owner-driven and fleet-driven.*
2) *For response functions for upfront or running costs: Result assuming the measure is applied nationally (all regions, all local authorities).*
3) *For response functions for running costs in restricted zones: Result assuming the measure is applied to defined restricted zones in various UK cities that were able to be modelled using the Streamlined PCM tool.*
4) *Result assuming the measure is assumed to begin implementation in year 2018. Larger impacts would be expected to occur for earlier start dates; smaller impacts would be expected to occur for later start dates.*

3.5 Example results for one response function: decreasing upfront costs of plugin cars

In order to highlight the detailed considerations for the response functions, this section provides further details for response function #1 (see Table 1) "decrease upfront costs of PHEVs and BEVs". The function can be used to estimate what changes may occur if the upfront costs of plugin-hybrid electric (PHEV) and battery electric (BEV) cars were reduced (which could, for example, represent a grant similar to the current availability of plugin car and van grants[15]).

Basis of the function

The response function and the evidence supporting it is fully described in Appendix 2. In summary, the response function estimates the impacts in 2020 only of changes in the composition of the car fleet. It does this through estimating the switching behaviour that could be expected to occur from conventional petrol or diesel powered Euro 6 cars to PHEV/BEV Euro 6 cars. The additional proportion of the car fleet estimated to have switched by 2020 to the PHEV/BEV cars is taken from literature for two given reductions in upfront costs, and then the impacts between these are extrapolated to provide a validity range of 0 to –20% change in upfront costs. The estimates from literature of the proportions of the fleet that switch vehicle types as a result of the cost changes are mapped on to the fleet mix in the Translation Tool.

Assumptions

The following assumptions were also made when developing this response function:

- Total car kilometres driven remains constant – i.e. the PHEV/EV cars are driven the same distances as the petrol or diesel engine cars that they replace; no rebound effect is assumed.
- Equal proportions of petrol and diesel cars switch to PHEV/BEV (central case).
- No impacts on the uptake of full hybrids.
- Nil impact is assumed on the pre-Euro 6 car fleet.
- Suitable levels of charging infrastructure to support additional EVs is assumed in place.
- Uncertainty bounds are based on two considerations:
    - ±50% of the changes in fleet composition for a given upfront price change, to reflect uncertainty in the future price premium of plugin cars over conventional petrol or diesel cars; and
    - the low estimate assumes only petrol cars are switched to PHEV/BEV; the high estimate assumes only diesel cars are switched to PHEV/BEV

Uncertainties

The degree to which car buyers would choose to switch their purchase to a PHEV/BEV from a conventionally fuelled car is uncertain. A key factor affecting this uncertainty is the "business as usual" projections of the uptake of PHEV and BEV vehicles – i.e. hence quantifying what the additional uptake could be with a reduction in their upfront costs. This relates to the price parity point between conventionally fuelled cars and PHEV and BEVs. Estimated price parity points are included in Figure 3. Aside from price, other key factors affecting this uptake uncertainty include: availability of charging infrastructure, perception of availability of charging infrastructure, availability of a range of models, vehicle distance range on one charge, relative prices of fuel and electricity, length of time to charge, availability of finance packages, battery life and associated warranties.

There is greater confidence in the response function up to upfront cost reductions of £3,000 as this was the highest value identified in the evidence base.

It is uncertain as to whether purchases would be switched from petrol or from diesel cars. Assessing this counter-factual of what vehicle would have been purchased otherwise without the reduced upfront costs of the PHEV/BEVs is challenging. This has an appreciable impact on air pollutant emissions.

[15] https://www.gov.uk/plug-in-car-van-grants/eligibility

There is a risk that the emission factors assumed for PHEVs do not reflect real world driver behaviour. The air quality benefits of PHEVs over conventionally fuelled cars (in particular diesel cars) are predicated on drivers utilising the plugin feature of the vehicles to charge up. If this is not carried out then the vehicle will simply be driving using the conventional engine.

Future emission rates of Euro 6 vehicles remain uncertain due to the limited evidence base available since their recent introduction to the fleet.

Results

The impacts of this response function on fleet composition are shown in Figure 3, assuming an equal split between PHEVs and BEVs.

The results of response function 1 on kilometres driven are shown in Table 2. These results are based on applying purchase cost change nationally across the UK. The kilometres driven of the vehicle types not affected (including Euro 6 petrol hybrid and Euro 6 diesel hybrid) are not shown. The results are split into sensitivities of scenario, purchase cost change, and proportion of PHEV of total plugin cars. An extreme sensitivity is also shown corresponding to the combination of variables that are estimated to have the lowest and highest impact on NO_X emissions.

Figure 3 Impacts of response function 1 on fleet composition of petrol and diesel cars (left hand y-axis) and on plugin cars (right hand y-axis)

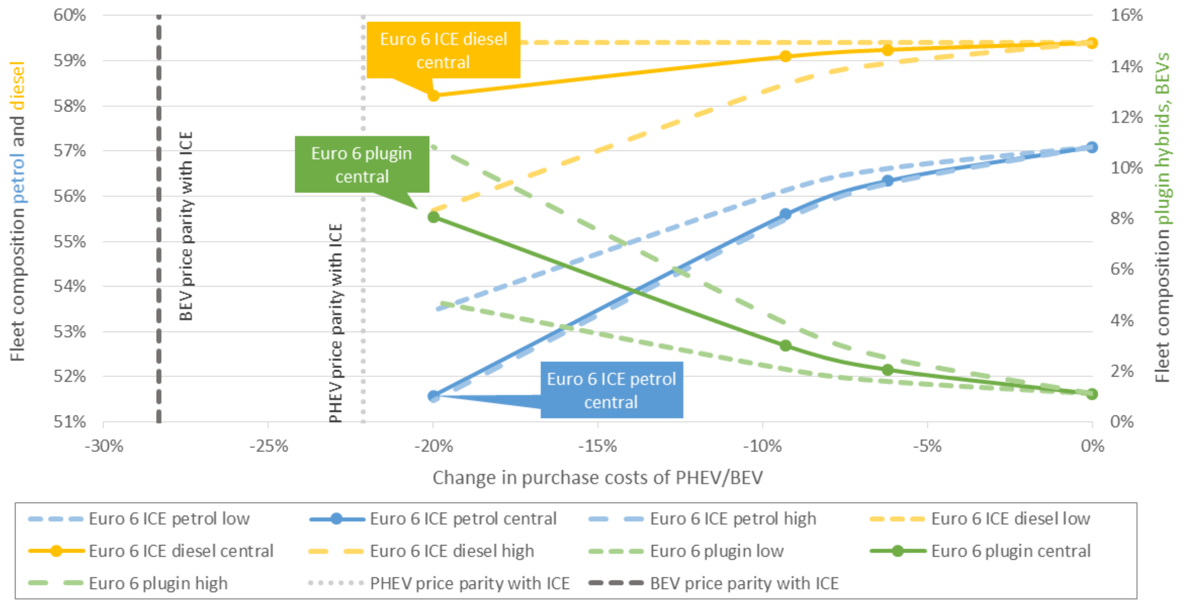


Table 2 Selected results for response function 1 on the vehicle fleet, applied nationally in the UK

#	Variables and inputs				Output: Euro 6 car kilometres (bn km)				Output: impact on total UK road transport NO_x emissions	Output: Average reduction across the 43 zones of the maximum annual mean NO_2 concentration (µg/m^3)	Output: Number of AQD zones brought into compliance
	Scenario	PHEV proportion	Purchase cost change (%)	Purchase cost change (£)	Petrol	Diesel	PHEV	BEV			
0	*Baseline*	-	-	-	*113*	*153*	*1.1*	*1.1*	-	-	-
Scenario sensitivity											
1	Low	50%	-10%	-£3,226	111	153	2.2	2.2	-0.06%	-0.01	0
2	Central	50%	-10%	-£3,226	111	151	3.3	3.3	-0.31%	-0.08	1
3	High	50%	-10%	-£3,226	113	146	4.4	4.4	-0.75%	-0.19	1
Purchase cost change sensitivity											
4	Central	50%	0%	£0	113	153	1.1	1.1	-	-	-
5	Central	50%	-2%	-£645	113	153	1.2	1.2	-0.03%	-0.01	0
6	Central	50%	-5%	-£1,613	112	152	1.7	1.7	-0.10%	-0.02	1
7	Central	50%	-10%	-£3,226	111	151	3.3	3.3	-0.31%	-0.08	1
8	Central	50%	-20%	-£6,452	106	146	8.3	8.3	-1.01%	-0.25	1
Proportion of PHEVs of total plugin cars sensitivity											
10	Central	0%	-10%	-£3,226	111	151	1.1	5.4	-0.33%	-0.08	1
11	Central	50%	-10%	-£3,226	111	151	3.3	3.3	-0.31%	-0.08	1
12	Central	100%	-10%	-£3,226	111	151	5.4	1.1	-0.28%	-0.07	1
Extreme sensitivity											
13	Low	100%	-20%	-£6,452	106	153	8.3	1.1	-0.15%	-0.04	1
14	High	0%	-20%	-£6,452	113	131	1.1	23	-2.57%	-0.63	3

The results for this function (Table 2) suggest that there may be very little benefit in switching Euro 6 petrol cars to PHEV/BEV compared to switching Euro 6 diesel cars (comparing nos. 1 to 0, and 13 to 8 in Table 2). It is also apparent that, due to the large uncertainty range in the function, even with a reduction of 10% upfront costs of PHEVs / BEVs, it may be that no additional air quality zones would be brought into compliance in 2020 (see no. 1 in Table 2). Many of the sensitivities are estimated to bring one additional air quality zone into compliance in 2020 (see nos. 2, 3, 6, 7, 8, 10, 11, 12, 13 in Table 2). The estimates of additional zones brought into compliance are strongly influenced by one zone projected in the baseline to be close to compliance however.

Many of the scenarios assume substantial increases in the kilometres driven of electric vehicles. Such deployment would most likely need to be supplemented by a commensurate increase in the provision of available charging infrastructure.

3.6 Limitations and uncertainty – implications for conclusions

There are many limitations of this work that are important to take into account when using and interpreting the results. Perhaps the most important overall caveat is that, even if one measure is evaluated to, or predicted to, have a particular effect and air quality benefit in one location, the same effect and impacts would not necessarily occur in another location. The limitations of this work are considered in three categories and summarised in the below tables as follows:

- Table 3 – Limitations of the evidence base;
- Table 4 – Limitations of the approach to developing the response functions; and
- Table 5 – Limitations of the Translation Tool and Streamlined PCM tool to estimate NO_X and NO_2 emissions and concentrations.

Further information on the limitations of the evidence identified from which response functions were drawn is included in Appendix 2. This appendix also includes further information on limitations of each response function.

Table 3 Limitations of the evidence base

Limitation	Implication
There is a general paucity of published quantified information of the effectiveness of many measures to reduce NO_2 and the associated costs and wider benefits of such measures. • Many published studies are impact assessments predicting potential outcomes. Real evaluated outcomes post implementation are often not reported. • There is a lack of evidence on the uptake rates of many of these measures. Assumptions are often made rather than a collecting primary research data to record the impact on behaviours.	Modelling and analytical work has to involve a greater number of assumptions and results have a higher degree of uncertainty. More ex-post evaluations of implementing measures aimed at improving air quality should be carried out and published (although it can be challenging to isolate and attribute changes specific to a certain policy or intervention rather than numerous other variables compared to the counterfactual).
In some cases, very limited evidence was identified relating cost changes to changes in kilometres driven, fleet composition and shifts to alternative modes of transport. • This is particularly the case for all vehicle types other than cars, for upfront costs and for low emission zones. • In contrast, there was extensive literature identified relating fuel cost changes with car usage (distance). • The findings have been based on the best available information identified and expert judgement.	There is low confidence in the response functions for LGVs, HGVs and buses & coaches, as some functions are based on only one or two data points. In many cases this is accounted by wide uncertainty ranges between the low and high scenarios of each response function. The results from the Translation Tool should be treated with care and as indicative only. The full uncertainty bands should be considered. The results should be used only as a screening tool prior to further analytical study of possible policy options to be taken forward.
Insufficient evidence was identified to separate out the effect of independently changing diesel from petrol costs on travel demand. The estimates are based on combined demand for both of these fuels.	It is not possible with this tool to assess the impact on driver behaviour if the price of diesel is varied with respect to petrol.
The response functions have been based where possible on long term elasticities. • The literature is inconclusive as to time periods associated with short run or long run elasticities. • It may take multiple years for the full effects of a policy to change travel behaviour. The impact of a policy in 2020 depends on when the policy came into effect and how long behaviour changes take to affect the market.	Care should be taken in interpreting the time period over which behavioural responses may occur. The estimated responses and hence NO_2 emission and concentration impacts may be overestimated for 2020 if it takes longer for the full behavioural changes to be realised.
The split between LGVs driven by owners and LGVs operated as fleets is not well known. Each of these subgroups has different running costs and would have different behavioural responses to changes in costs.	The tool has a default assumption of 50:50 split between these driver types, but for the full range of uncertainty on impacts on LGVs Defra should use a range of assumptions on this split from 25:75 to 75:25.

Table 4 Limitations of the approach to developing the response functions in the Translation Tool

Limitation	Implication
No primary research or modelling has been undertaken. • The response functions have been based on evidence from experts and identified in literature. • Members of the expert panel recommended carrying out primary research were there more time available (e.g. asking user groups to identify their likely behavioural responses to a hypothetical policy) and national/regional modelling of demand for vehicle ownership. Modelling could support or replace the response function approach.	The response functions have higher uncertainties and lower confidence than if they had been supported by a wider evidence base of also primary research and/or modelling. As such, the results should be used only as a screening tool prior to further analytical study of the policy options to be taken forward. Further modelling and primary research is recommended to confirm and validate the likely behavioural responses, including geographical variations of this for specific policy measures. Detailed transport modelling at local or regional level could account for the complexities of local situations that the simple approach with response functions does not account for.
Daily costs for each vehicle type are based on average mileages across the UK population. • No disaggregation of the population is considered for variations in fuel costs. • Behavioural responses are likely to be strongly linked to daily fuel costs.	Daily fuel costs vary considerably across the population and so the behavioural response functions that have been estimated will not reflect the range of responses that would follow from the range of different mileages. This may overestimate or underestimate responses. Behavioural responses would be better estimated if the population is disaggregated.
The tool does not easily allow the effects of multiple response functions to be considered together. Each of the response functions has been estimated on its own basis.	Combining the effects from multiple response functions affecting one vehicle type is not possible as there may be interactions between measures that have not been accounted for. E.g. adding together fuel duty and LEZ. However, the effects of multiple response functions on different vehicle types may be additive and therefore possible to combine, if the behavioural responses between the vehicle types do not affect each other (e.g. LEZ for cars and LEZ for HGVs).
The response functions only represent measures that affect vehicle economics. This excludes other measures that may improve local air quality (e.g. strategies to reduce demand and/or smooth traffic flows around hotspots).	The tool cannot be assumed to be comprehensive in terms of the options available for improving local air quality.
The response functions and the tool are limited to estimating impacts in 2020.	Air quality effects of the measures for other years cannot be estimated in the tool without further work.
No modal shift between LGVs and HGVs, or among HGV size categories, is considered. E.g. a measure increasing HGV running costs could lead to a change in freight distribution or other commercial practices, by increasing activity by LGVs if LGVs are not also targeted by a similar measure.	Modal shift spillover impacts such as these should be considered in further modelling, depending on the policy option.

Table 5 Limitations of the Translation Tool and Streamlined PCM tool to estimate NO_X and NO_2 emissions and concentrations

Limitation	Implication
The approach does not estimate impacts on emissions from traffic on category B/C/minor roads. Emissions (and estimated emission reductions) are for major roads only (A roads and motorways).	In practice emission reductions would be expected on B/C/minor roads too, so the tool underestimates possible emission reductions. However, the highest NO_2 concentrations are expected to occur at major road receptors and will therefore most influence compliance with AQD limit values.
There is high uncertainty in the actual emission levels of Euro 6 vehicles. • Conformity factors are the ratio of real world emission levels to Euro standard limits. • The scenario used in the Streamlined PCM tool assumes conformity factors of 2.8 for passenger cars, 2.21 for N1 Class II LGVs and 1.86 for N1 Class III LGVs.	Emission estimates are affected by these conformity factors. Actual emissions could be higher or lower, depending on how the Euro standards actually deliver, which may mean this tool overestimates or underestimates the emission reductions.
Projections for unconventional technologies such as electric and plug-in hybrid vehicles are highly uncertain.	The effect of measures in reducing NO_X might change depending on the real uptake of unconventional technologies in future years.
Average speed-related emission factors have been used for different road types, in line with the NAEI. • This approach is unsuitable for estimating changes in emissions arising from relatively small changes in speed. No account is made for emission impacts due to changes in speeds of vehicles. • Average speed-dependent curves for the estimation of emission factors have been determined for the different engine sizes of passenger cars and weights of HGVs, buses and coaches.	Measures that affect urban traffic flows and congestion may result in quite small changes in average speed, but larger effects on the dynamics of the general traffic situation (more or fewer stop-starts etc.) which can have a large effect on emissions. A different type of traffic emissions model is needed for this kind of application, one based on second-by-second vehicle emission simulation modelling. If engine size/weight considerations change, the average speed-dependent curve for that particular vehicle and fuel type will no longer be valid.
Latest evidence suggests that the emission factors for hybrid diesel cars are effectively the same as those of conventional diesel cars.	No NO_X emissions benefit is reflected by the tool when one conventional diesel car is substituted by a hybrid diesel equivalent.
Emission benefits of PHEV depend on user charging behaviour. The air quality benefits of PHEVs over conventionally fuelled cars (in particular diesel cars) are predicated on drivers utilising the plugin feature of the vehicles to charge up. If this is not carried out then the vehicle will simply be driving using the conventional engine.	Emission benefits for measures with PHEVs may be over or under estimates. Emissions from the generation of the electricity (emitted elsewhere) are not accounted for.

Limitation	Implication
Taxis are considered within conventional diesel passenger cars and only for road links inside Greater London.	Measures specific to taxis cannot be easily considered. Applying measures specifically to taxis has to be modelled as an adaptation of a measure applied to diesel passenger cars and only for the road links within Greater London.
Emission and concentration modelling with the Streamlined PCM tool requires specific information about the baseline years and the outputs of the full PCM model for each baseline.	This fact limits the assessment capabilities to only the specific years of the considered baselines. 2020 is the only year for which the current version of the Translation Tool and Streamlined PCM tool estimates emissions and concentrations. The tools could be further developed however to estimate projections for other years.
This study has focussed only on measures addressing road transport because of the strong link between contribution of emissions from road transport and exceedances of the Ambient Air Quality Directive NO_2 limit values.	The tool does not consider possible measures for other sectors. Sectors other than road transport also contribute to NO_2 exceedances and so could also in some cases be targeted to improve local air quality.

4 Conclusions

The rapid evidence review flagged up 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 in travel choices or emissions abatement has been assessed in some way. At this point in time, numerous local authorities throughout the UK have adopted different policy packages in an effort to improve air quality and comply with the European limit values for NO_2. In many cases these efforts have not been sufficient and/or have not achieved the desired outcomes for a variety of reasons, as evidenced by the continuous non-attainment of the limits within various air quality management zones. It is therefore critical to focus future policy making on those measures that have the greatest potential with regards to sustained emissions abatement whilst at the same-time delivering these reductions in a cost effective manner.

Findings from the project demonstrated that there is a role for preferential use of locally targeted measures for improving air quality, as opposed to national 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 larger or city-wide schemes, rather than focused solely on NO_2 hot-spots (although some of this may simply relate to the feasibility or application or implementation). This site-specificity highlights the need for assessing the effectiveness of each measure in its local context and avoiding making assumptions that schemes can be easily transferred and lead to the same benefits. Locally targeted measures rather than national measures do not impose costs on drivers and operators that are not travelling in and contributing to poor air quality in zones of non-compliance.

The evidence reviewed on effectiveness of measures to reduce NO_2 concentrations identifies many measures as potentially providing effective reductions. In particular, packaging multiple complementary measures to address specific local conditions can be very effective for achieving air quality benefits alongside providing additional local benefits such as reduced congestion, noise, and economic development. Traffic management and access control measures focussed on restricting use of the main local sources of NO_2 emissions (diesel vehicles) can be very effective, although costly, and need to be handled case by case. Demand management measures and measures to encourage modal shift, when paired with sustained information campaigns, can be cost effective. Promotion of low emission vehicles can also be effective in delivering air quality improvements but only if uptake rates are substantial, and if real world emissions of the vehicles are substantially lower than of the vehicles they replace. Pricing mechanisms, such as shifting taxation to favour vehicles with lower NOx emissions, can be cost effective although there may be negative impacts on social equality.

There were significant evidence gaps in the literature to fully address many of the research questions. There is a general paucity of quantified information of the effectiveness of many measures to reduce NO_2 and the associated costs and wider benefits of such measures. The real evaluated outcomes post implementation of measures are not frequently reported. There is also a lack of evidence on the uptake rates of many of these measures, and assumptions are often made rather than a collection of primary data to record the impact on behaviours.

As such, an alternative approach was taken to estimate the impacts of measures, based on changes in vehicle economics, with measures grouped into three broad cost categories. A number of response functions were developed, characterised by changes in vehicle demand (in terms of distances driven, fleet composition and modal shift), for each vehicle type and cost change type. These response functions were used in a tool (the 'Translation Tool') developed in this project to transform these cost changes into vehicle and fleet changes. The Translation Tool can be combined with the Streamlined PCM tool, also developed as part of this project, in order to estimate the NO_X emission and roadside NO_2 concentration impacts of these measures. The tool developed provides Defra with the ability to estimate impacts of measures at multiple geographic scales – whether by region, local authority, defined urban areas or for individual roads.

As expected, there are a number of caveats associated with this approach, given the limited evidence base. The results estimated in the tool are to be interpreted as indicative only, and more detailed analysis should be carried out on potential policy options that are to be considered further. Primary research and dynamic modelling (for example by the DfT using their National Transport Model and car ownership model) could build on the evidence identified as part of this project, focussing on the most significant gaps in knowledge, although such models would need further development and investment before being used for this means. The evidence base was stronger for estimating the impacts when running costs of cars change, but weaker for estimating most other effects (other vehicle types and other cost types).

The tool is designed to estimate road transport and NO_X and NO_2 impacts only, and does not currently consider cross-impacts – whether there may be additional pollutant burdens or co-benefits. Congestion and GHG impacts are not considered but could play important roles in affecting overall acceptability and cost effectiveness. The tool is limited to evaluations of effectiveness of air quality in terms of NO_2 impacts, not cost-effectiveness.

Whilst the tool enables the assessment of the possible impacts of single policy measures only, the literature and expert panel highlighted that the highest emission reductions in urban areas may be achieved by integrated strategies combining multiple measures pursued and sustained over a long period of time. 'Stick measures' (higher pricing or access restrictions) can become more acceptable and effective when accompanied by supportive measures to encourage alternatives (public transport, walking, cycling, smarter choices, urban design, parking).

Appendices

Appendix 1 Evidence review of measures to reduce roadside NO_2 concentrations

Appendix 2 Evidence review and expert elicitation exercise on behavioural responses to changes in vehicle economics

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