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An Economic Analysis to inform the Air Quality Strategy
Updated Third Report of the Interdepartmental Group on Costs and Benefits

Volume 3

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Department of Environment, Food and Rural Affairs in partnership with the Scottish Executive, Welsh Assembly Government and Department of Environment Northern Ireland

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Introduction

The 2007 Air Quality Strategy for England, Scotland, Wales and Northern Ireland contains targets for reductions in the concentrations of nine major pollutants, to be achieved between 2010 and 2020. In doing so it replaces the previous 2000 Air Quality Strategy and its 2003 Addendum[1].

The Air Quality Strategy (AQS) review, published in April 2006, assessed the possible impacts of a range potential future policy measures to help achieve the existing objectives. As a secondary consideration it also reviewed the existing objectives and proposed changes to some objectives. This review informed the development of the new 2007 Air Quality Strategy published alongside this report.

The Interdepartmental Group on Costs and Benefits (IGCB) is tasked with undertaking the formal economic analysis of air quality policy underpinning the new AQS and therefore the aim of this report is to present both the methodology and results of this analysis.

The previous version of the Third IGCB report incorporated two major pieces of research into the IGCB methodology used in the assessment of possible impacts of air pollution: Valuation of Health Benefits Associated with Reductions in Air Pollution'[2] and 'An Evaluation of the Air Quality Strategy'.[3]

In May 2004, Defra published a report on 'Valuation of health benefits associated with Reductions in air pollution'. This detailed the findings of a research project that used survey-style contingent valuation methods to elicit a range of monetary values for various key mortality and morbidity benefits. Following the publication of this report, an expert workshop on the Valuation of Health Benefits of Reductions in Air Pollution and Use of Values in Appraisal was held in June 2004.[4] The recommendations of this workshop informed an IGCB paper that sought to agree the valuation of health benefits in policy appraisal. These recommendations were agreed interdepartmentally and therefore form the basis of the valuation of health benefits within the current analysis. The monetary valuation of health benefits represents a major development in the IGCB methodology.

The IGCB also contributed to the scoping and management of a Defra-sponsored research project that evaluated selected air quality policies in the road transport and electricity supply industries, from 1990 onwards.[5] The main conclusions that can be drawn from this study are:

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1 'The Air Quality Strategy for England, Scotland, Wales and Northern Ireland: Addendum', Defra, (2003). Available at http://www.defra.gov.uk/environment/airquality/strategy/addendum/pdf/aqs_addendum.pdf

2 Chilton et al (2004) 'Valuation of Health Benefits Associated with Reductions in Air Pollution'. Available at http://www.defra.gov.uk/environment/airquality/valuation/index.htm

3 'An Evaluation of the Air Quality Strategy' Defra, (2005a). Available at http://www.defra.gov.uk/environment/airquality/strategy/evaluation/report-index.htm

4 A summary of the workshop proceedings can be found at http://www.defra.gov.uk/environment/airquality/valuation/workshop.htm

5 'An Evaluation of the Air Quality Strategy' Defra, (2005a). Available at http://www.defra.gov.uk/environment/airquality/strategy/evaluation/report-index.htm

- Policies in both the transport and electricity supply industries have led to major emissions reductions;
- The policies have generated large estimated benefits in reducing health and environmental impacts;
- There are good benefit to cost ratios for the air quality policies that have been implemented in both sectors i.e. when comparing estimated actual benefits from policies against the 'ex post' costs; and
- For many, although not all, policies, the ex-post implementation costs have been less than the predicted costs ex-ante.

The findings from both of these studies have been used to inform and develop the IGCB methodology detailed in this report.

This update builds on the analysis in the previous IGCB report in two significant ways:

- Firstly by updating the existing measure and where appropriate introducing new measures in light of recent developments and information received during the AQS consultation period. For convenience any changes in the analysis have been highlighted at the beginning of each chapter; and
- It also extends the IGCB methodology to include sensitivity analysis using Monte Carlo techniques. This analysis allows the impacts of measures to be focused by using the underlying probability distributions associated with some key sensitivities.

Methodology for the monetary cost benefit analysis

A monetary cost benefit analysis (CBA) forms a major part of the overall assessment of the measures being considered for the strategy although other impacts that cannot be either quantified or valued (e.g. exceedences of current limit values, ecosystem effects) are also presented. All impacts, not only those that form part of the monetary CBA, should be taken into account when assessing the relative merits of the measures.

The monetary assessment of benefits is based on the impact-pathway approach that follows a logical progression from emissions through dispersion, concentration and exposure to quantification of impacts and their valuation. The benefits are then compared on a consistent basis with the costs associated with the implementation of each of the policy measures.

There are uncertainties associated with every stage of the impact-pathway approach: estimating emissions and concentrations, quantifying and valuing benefits (especially health impacts) and estimating costs, and the results of this analysis need to be interpreted with this in mind. In some instances, it has been possible to incorporate ranges into the central estimates of the monetary CBA to account for some of these uncertainties. Chapter 5 (Uncertainties and sensitivity analysis) also provides further detail, discussing uncertainty in both qualitative and quantitative terms. This chapter now includes the results of a Monte Carlo analysis carried out to assess how selected uncertainties and key assumptions affect the distribution of costs and benefits. The full analysis of which is provided in Annex 7.

Quantification of emissions and concentrations

The assessment of current and future air quality is undertaken through a combination of both measurement and modelling. A range of models is used to project air quality based on estimates of the emissions of a variety of air pollutants. The modelling of air quality is challenging because of the difficulty in modelling the complex chemical reactions and physical processes in the atmosphere and the diversity and complexity of emissions sources and emissions rates. There are therefore important uncertainties surrounding the resultant estimates.

The measures considered in this report have been assessed compared to the baseline. This takes account of the expected changes in air pollution as a result of current policies and agreed and planned future polices, such as the implementation of the Large Combustion Plant Directive and European directives on vehicle emissions and fuel quality. The estimation of air quality for the baseline and the future potential measures provides the basis for an assessment of the impact on exceedences of current and future objectives, as well as input into the analysis of changes in air quality in terms of impacts on health, the environment and buildings.

A baseline assessment has been carried out for all the pollutants targeted within the AQS, providing estimates of the impact of current and future agreed legislation on air quality in 2005, 2010, 2015 and 2020. Emissions of both sulphur dioxide (SO_2) and oxides of nitrogen (NO_X) are expected to continue their long term decline. However, without further action, emissions of other pollutants are unlikely to follow a downward trend: emissions of ammonia are expected to remain relatively constant after 2010, emissions of both non methane volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs) are expected to increase after 2010 and emissions of particles (PM_{10}), fine particles ($PM_{2.5}$) and benzene are expected to rise after 2015. Emissions projections are uncertain, particularly beyond 2015.

In terms of the baseline assessment of the AQS objectives, some of these are very challenging to achieve everywhere and will remain so without further measures. We are confident that the 2010 annual mean PM_{10} objective for London, the rest of England, Wales, Scotland and Northern Ireland and the 2005 nitrogen dioxide (NO_2) annual mean objective will not be met everywhere, particularly near to many urban roads. We are also confident that the 2005 ozone daily maximum 8-hour mean will not be achieved. It is possible that there will be exceedences of the 2010 PAH annual mean objective in some locations, although this is more uncertain. Other objectives, including the SO_2, benzene, 1,3-butadiene, carbon monoxide (CO) and lead objectives, are being met or are likely to continue to be met by their objective years. Modelling also shows that the existing objectives for ecosystems (for oxides of nitrogen and sulphur dioxide) are currently being met and will continue to be met during the period to 2020.

A key change in the estimation of concentrations relates to the formation of secondary particles (sulphates and nitrates). Following recent scientific evidence, it has been concluded that the rate of formation of secondary particles does not follow at the same rate as the increase in their precursors (SO_x and NO_x). The estimation of secondary particle concentrations has been amended accordingly.

Quantification and valuation of benefits

There is strong evidence from statistical correlations that air pollution at current levels typical in the United Kingdom damages health. One of the major purposes of the AQS is to ensure protection against risks to public health from air pollution. Healthy individuals are not thought to be at significant risk of short term effects from current levels of air pollution in the UK, but statistical studies have indicated associations, which persist at relatively low levels, between daily variations in levels of some pollutants and daily variations in mortality and hospital admissions for respiratory or cardiovascular conditions. The effects of particles, SO_2 and ozone have all been quantified and valued as part of the central estimates for this review.

The quantification of health effects uses concentration-response functions that link concentrations of the major pollutants with effects on health. The concentration-response functions used within this analysis are those recommended by the Department of Health's Committee on the Medical Effects of Air Pollutants (COMEAP).[6] The health effects considered include both short term effects (daily deaths, respiratory and cardiovascular hospital admissions) and long term effects. There is, however, considerable uncertainty surrounding the precise scale and mechanisms linking air quality and health, especially for the long term effects on life expectancy.

Evidence indicates that long term exposure to background levels of $PM_{2.5}$ is the most important effect of air quality on public health. For these long term effects, COMEAP published an updated interim statement in 2006[7] recommending a hazard rate reduction of 6% per 10μg.m^{-3} $PM_{2.5}$. The COMEAP Interim Statement replaces its previous report published in 2001 (see footnote 6), which considered a 0.1% hazard rate reduction (i.e. a 1% drop in mortality rate per 10μg.m^{-3} $PM_{2.5}$) to be "most likely", with a 0.3% hazard rate reduction "reasonably likely" and a 0.6% hazard rate reduction "less likely". The analysis presented in Chapter 3, and in summary throughout the report, has been updated to reflect this latest recommendation.

This hazard rate consistent with the hazard rate used in the recent analysis of the health impacts of air pollution in Europe for the CAFE Thematic Strategy. COMEAP also recommended a 'typical low' value and a 'typical high' value as the median[8] of the lowest quartile (1%) and the highest quartile (12%) respectively. These values have therefore been incorporated into the sensitivity analysis in Chapter 5. The full distribution of coefficients is illustrated in Figure 5.1 in Chapter 5 of this report.

The quantified health impacts (deaths brought forward, life years lost, hospital admissions) have been valued using the values recommended by IGCB and agreed interdepartmentally. The central values are £29,000 per life year lost in 'good' health, £15,000 per life year lost in 'poor' health and £1,900-£2,000 per hospital admission (2004 prices). These values have been converted to 2005 prices and uplifted each year to reflect the assumption that willingness to pay will increase in line with long term economic growth at 2%. All valued benefits have been discounted using the recommendations in the HM Treasury Green

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6 Department of Health (1998; 2001a; 2001b; 2006b). All available at: http://www.advisorybodies.doh.gov.uk/comeap/state.htm

7 'Interim Statement on the Quantification of the Effects of Air Pollutants on Health in the UK', Committee on the Medical Effects of Air Pollutants, Department of Health (2006b). Available at www.advisorybodies.doh.gov.uk/comeap/pdfs/interimlongtermeffects2006.pdf

8 The 12.5^{th} and 87.5^{th} percentiles of the whole distribution. Department of Health (2007).

Book[9] and the resultant net present values have then been annualised. This is to facilitate comparison between policies with differing lifetimes.

A number of non-health benefits have also been included in the monetary CBA – i.e. direct effect of ozone (O_3) on crop yields, material damage from SO_2 and ozone, PM buildings soiling. In addition, a number of measures have carbon impacts as well; these have been valued using the current guidance on the social cost of carbon and included in the monetary assessments of these measures.

Following the full impact-pathway process in its entirety is resource intensive. Therefore, for a number of policies, the benefits have been assessed on the basis of emissions only. Estimates of the impacts and monetary values per tonne of pollutant have been applied to the projected emissions for these scenarios, using different estimates for different sectors. These estimates are themselves derived using the impact-pathway approach and take account of human exposure to pollutants, exposure of crops to ozone and damage to materials.

Costs

Costs have been presented in terms of the impact to society as a whole and therefore do not take account of transfers between different sectors (e.g. taxes and subsidies) or accounting costs such as depreciation. The costs are presented in 2005 prices and have been adjusted for inflation assuming a rate of 2.5% per annum. As with benefits, costs have been discounted using current HM Treasury Green Book guidelines and are presented on an annualised basis.

For industrial and domestic-related measures, both capital costs, such as those associated with the fitting of selective catalytic reduction, and changes to operating costs are included. The assessment of transport-related costs takes account of the costs of new technology, the resource costs due to a change in fuel use and the welfare effect due to any change in kilometres travelled. Therefore, as far as possible, the costs include both financial costs and wider welfare impacts.

Where possible cost assumptions have been refined in light of responses received during the AQS review consultation in 2006 and where better information has become available. This is discussed, for applicable measures, in Chapter 3.

Results of the monetary cost benefit analysis

A number of measures have been assessed, covering transport, industrial, domestic and shipping sectors: these are outlined in Table E.1 below and described in more detail in Chapter 3 and Annex 5. Some of these measures have a relatively short term impact whilst others are likely to result in a sustained drop in pollution over the long term. Additional measures in this update (A2, C2 and R) have also been introduced and assessed in light of recent developments since the AQS review consultation. The way in which these measures are assessed has taken these differing timescales into account; all monetary results are shown in £m per annum in 2005 prices to facilitate comparison.

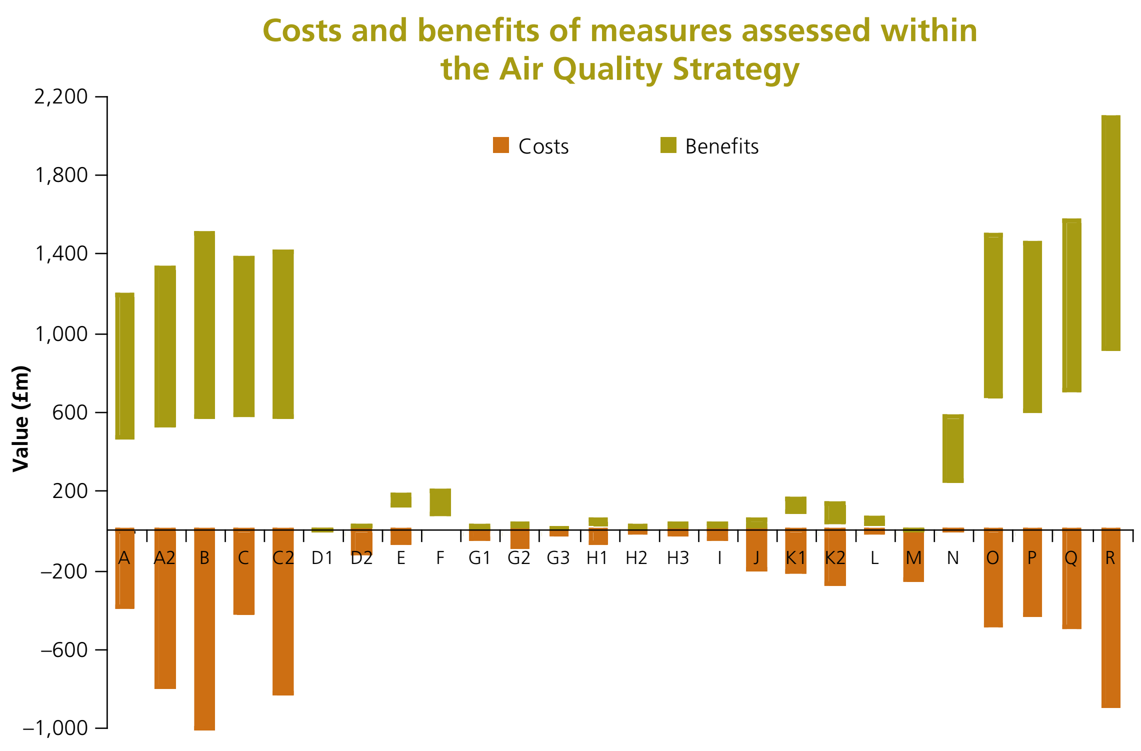
[9] 'The Green Book: Appraisal and Evaluation in Central Government', HM Treasury (2003).

Table E.1: Description of measures assessed within the review of the AQS

Measure	Description
A (Euro low)	New Euro standard 5/VI – Low intensity
A2 (Euro revised)	New Euro standard 5/6/VI – Revised scenario
B (Euro high)	New Euro standard 5/6/VI – High intensity
C (Early Euro low)	Incentivising early uptake of Euro 5/V/VI standards based on Measure A (Euro low)
C2 (Early Euro revised)	Incentivising early uptake of Euro 5/V/VI standards based on Measure A2 (Euro revised)
D (Phase out)	Programme of incentives to phase out the most polluting vehicles (e.g. pre-Euro). Two versions of the measure have been assessed.
E (LEV)	Increased uptake of low emission vehicles
F (Road pricing)	Impact of a national road pricing scheme on air quality
G (LEZ)	Low emissions zone in London and 7 largest urban areas. Three versions of the measure have been assessed
H (Retrofit)	Retrofit Diesel Particulate Filters on HDV and captive fleets (buses and coaches). Three different versions have been assessed.
I (Domcom coal)	Domestic combustion: switch from coal to natural gas or oil
J (Domcom NO_X)	Domestic combustion: product standards for gas fired appliances which require tighter NO_X emission standards.
K (LCP)	Large combustion plant measure. Two elements of this measure have been assessed separately.
L (SCP)	Small combustion plant measure
M (VOC)	Reducing national VOC emissions by 10%
N (Shipping)	Shipping Measure through IMO
O (Early Euro low + LEV)	Combined measure
P (Early Euro low + SCP)	Combined measure
Q (Early Euro low + LEV + SCP)	Combined measure
R (Early Euro revised + LEV + Shipping)	Combined measure

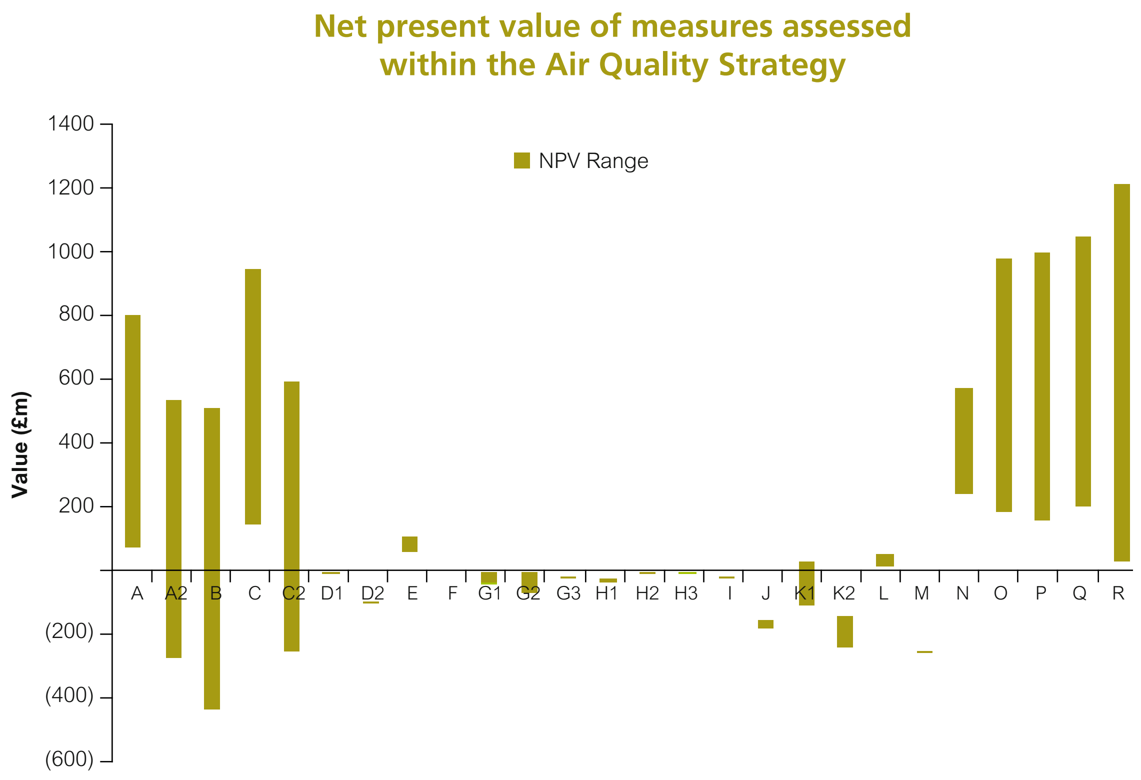
The costs and benefits of the policy measures are shown graphically in Figure E.1. This allows for measures that have the greatest potential benefits, but also higher costs, such as Measure B, to be more easily identified. The benefits are presented as a range, largely driven by the differing assumptions relating to lag times between changes in exposure and effect on life expectancy. The lower bound of the ranges in the graph below represents the PV of benefits at the 6% hazard rate (per 10µg.m^{-3}) with the 40 year lag and the upper bound represents the PV of benefits at the 6% (per 10µg.m^{-3}) hazard rate with no lag. It should also be noted that the costs are presented as bars between the cost estimate, which are generally point estimates, and a value of zero. Costs are presented in this way to ensure visibility as point estimates or limited ranges are not clear on the diagrams scale. Therefore it should not be read that all costs have at the bottom of their range a zero cost.

Figure E.1 Description of measures assessed within the review of the AQS



The net present values resulting from the monetary CBA are also shown graphically in Figure E.2 below. As with Figure E.1, the lower bound of the ranges in the graph below represents the NPV at the 6% (per 10µg.m^{-3}) change in hazard rate with the 40 year lag and the upper bound represents the NPV at the 6% (per 10µg.m^{-3}) change in hazard rate with no lag. The latest statements from COMEAP suggest that, although evidence was limited, the Committee's judgement tends towards a greater proportion of the effect occurring in the years sooner after the pollution reduction rather than later. This would mean that the effect is more likely to be nearer the no lag result.

Figure E.2



There are a number of measures that are favourable in monetary cost benefit terms across the full range of assumptions incorporated in the central analysis. These include Measures A (Euro low), C (Early Euro Low), E (LEV), L (SCP), N (Shipping), and combined measures O, P, Q and R.

There are other measures, however, that have a negative net present value at the lower end of the range but a positive net present value at the upper end of the range. These include Measure A2 (Euro revised), Measure B (Euro high), Measure C2 (Early Euro revised), Measures H2 and H3 (Retrofit) and Measure K1 (LCP). The recent advice from COMEAP i.e. that results towards the upper end of the benefits range are considered more likely, should be borne in mind when assessing these results.

Measure D (Phase out), Measure G (LEZ), Measure H (Retrofit), Measure I (Domcom coal), Measure J (Domcom NO_X), Measure K2 (LCP), and Measure M (VOC) show negative annual net present values and are therefore less preferable according to this assessment. This however does not mean that these measures could not provide significant benefits for example by helping achieve legally binding EU limit values.

Non-monetary assessments

There are a number of impacts that result from air quality policies that cannot be valued and therefore are not included in the monetary cost benefit results. The results from such assessments may, however, be important when considering the relative merits of the different measures and therefore should be considered along with the CBA.

Exceedences

The emissions and concentration modelling allows the impact on exceedences of AQS objectives to be analysed. These impacts are assessed both at background and at urban roadsides in 2010 and 2020. Background concentrations are indicative of the population's exposure to the pollutants and hence the health impacts. Roadside concentrations are indicative of peak concentrations or 'hotspots', regardless of possible exposure.

The background assessment shows the modelled percentage change to the area of the United Kingdom that exceeds the relevant objective, and therefore reflects average concentrations of the pollutant away from roads. The urban roadside assessment shows the modelled percentage change to the length of urban roads in the UK that exceed the relevant objective and therefore reflects concentrations close to urban roads.

Three objectives have been considered: the 2005 NO_2 40µg.m^{-3} annual mean,[10] PM_{10} $<$31.5µg.$^{-3}$ and $<$20µg.$^{-3}$ annual mean objectives for England, Wales and Northern Ireland, excluding London and Scotland.[11] The PM_{10} $<$31.5 µg.$^{-3}$ objective is seen as equivalent to the PM_{10} 24 hour mean objective that is used hereon in.

In terms of roadside exceedences of the NO_2 annual mean objective, the most effective measures are Measures A2, (Revised Euro low), B (Euro high), C2 (Revised Early Euro low), O, P, Q and R (combined measures). These are projected to reduce exceedences at roadsides by around 50% in 2020. None of the measures are likely to remove all exceedences of this objective in 2020.

To address roadside exceedences of the PM_{10} $<$31.5µg.$^{-3}$ annual mean objective, the most effective measures are Measures A (Euro low), A2 (Revised Euro low), B (Euro high), C (Early Euro low), C2 (Revised Early Euro low) O, P, Q and R (combined measures). These are projected to eliminate all exceedences at the roadside of the 24 hour PM_{10} objective in 2020. This compares to the baseline where exceedences are 0.3% of urban road length. Measures N (Shipping) and F (Road pricing) might have a significant impact on exceedences but are not projected to remove them completely. The remaining measures are likely to have no impact in 2020.

There are widespread roadside exceedences of the PM_{10} stage 2 indicative limit value in the baseline. The most effective measures are Measures B (Euro high), C (Early Euro low), O, P, Q and R (combined measures). These might reduce exceedences by over 50%, although no measures are likely to achieve 20µg.m^{-3} at roadsides everywhere.

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[10] Equivalent to the 2010 EU limit value in the First Air Quality Daughter Directive.

[11] Equivalent to the Stage 2 indicative limit value in the First Air Quality Daughter Directive (20µg.m^{-3} annual mean).

In terms of background exceedences, only the PM_{10} stage 2 indicative limit value is projected to be exceeded at background in 2010 and 2020. The most effective measures are Measures A (Euro low), A2 (Euro revised), B (Euro high), C (Early Euro low), C2 (Early Euro revised) O, P, Q and R (combined measures). These might reduce exceedences by over 50%, although no measures are likely to achieve 20µg.m^{-3} everywhere.

Ecosystem assessment

The projected deposition of oxidised sulphur compounds (SO_X), oxides of nitrogen (NO_X) and reduced nitrogen compounds (NH_X) has been modelled for future years and then compared with critical loads to determine excess deposition of pollutants that might have an adverse impact on ecosystems.

The results are presented in terms of both acidity and nutrient nitrogen. For each of these, both the projected area exceeded for critical loads (km^2) and the accumulated exceedence of critical load (keq/yr) is reported for 2020.

Based on this analysis of the measures that have a significant positive impact, Measures B (Euro high), K (LCP), O, P, Q and R (combined measures) have the greatest benefits in terms of acidity and nutrient nitrogen.

Additional health impacts

There are a number of health impacts that cannot be quantified and are therefore not included in the central monetary cost benefit analysis. For some of these, there is a general consensus as to a link with certain pollutants and some evidence to allow judgements on which measures are most important for the relevant pollutant. Such health impacts have been included in the qualitative assessment and include the possible effects on leukaemia from benzene and 1,3-butadiene, the possible effects on lymphoma from 1,3-butadiene and the possible effects on lung cancer from PAHs.

On the basis of such a qualitative assessment, Measure D (Phase out) may result in a small decreased risk of leukaemia and lymphoma (due to reductions in both benzene and 1,3-butadiene), and Measure I (Domcom coal) may result in a small decreased risk of lung cancer (due to reductions in PAHs).

Noise

It is expected that noise benefits will be extremely small in relation to other benefits. Measures D (Phase out), E (LEV), F (Road pricing), G (LEZ), O, Q and R (combined measures) have been identified as having potential beneficial effects on noise.

Distributional (social) impacts

The existing evidence linking air quality and distributional (i.e. social and socio-economic) effects has been assessed and used as the basis of a qualitative assessment of the measures included within this review.

There is some evidence from limited UK studies (King and Stedman 2000;[12] Pye 2001)[13] that shows that air pollution exposure is higher amongst some communities who rate poorly on social deprivation indices. This work was limited in scope, covering only five urban areas in the UK. An ongoing comprehensive study for the whole of the UK is due to be completed in the near future. Interim analysis of this study suggests that the associations between poor air quality and deprived areas are complex and depend on the pollutant in question.

Given these findings, it is difficult to provide robust conclusions as to the likely impact of the measures within this review in terms of distributional impacts i.e. effects on more deprived areas. Measures D (Phase out), G (LEZ) and I (Domcom coal) have been identified as having effects that are probably particularly beneficial in more deprived areas or to lower income groups. Measures A (Euro low), A2 (Euro revised) B (Euro high), C (Early Euro low), C2 (Early Euro revised), E (LEV), F (Road pricing), H (Retrofit), J (Domcom NO_X), L (SCP), O, P, Q and R (combined measures) have possible beneficial effects in terms of distributional impacts although these are likely to be small.

Competition and small business assessment

An initial assessment of possible competition effects and impacts on small businesses has been undertaken. However, it has not been practicable to undertake a full, detailed assessment across all affected markets. Therefore, the likely competition and small business impacts have been assessed in mainly qualitative terms based on a quantitative and qualitative understanding of the affected markets, the current market structure and nature of competition and the likely positive and negative impacts of the possible policy measures.

Any measures that are taken forward at the conclusion of this review will be subject to a full individual impact assessment (IA) that will assess the competition and small business issues in more detail

The results from the initial analysis have highlighted Measures G (LEZ), I (Domcom coal), and K (LCP) as having competition issues that may warrant further investigation although without a more detailed understanding of implementation options it is difficult to clearly assess the effects. In addition, there may be other measures that, when analysed in more detail, may raise competition concerns.

Measures G (LEZ), I (Domcom coal), L (SCP), P and Q (combined measures) have been identified as having possible disproportionate impacts on small businesses that need to be assessed in more detail.

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[12] King, K. and Stedman, J. (2000) 'Analysis of Air Pollution and Social Deprivation', Contract report for the Department for the Environment, Transport and the Regions, The Scottish Executive, The Welsh Assembly and the Department of Environment for Northern Ireland. Available at http://www.airquality.co.uk/archive/reports/cat09/aeat-r-env-0241.pdf

[13] Pye, S. (2001) 'Further Analysis of NO_2 and PM_{10} Air Pollution and Social Deprivation', Available at http://www.aeat.co.uk/netcen/airqual/reports/strategicpolicy/2001socialdeprivation_v4.pdf

Uncertainty and sensitivity analysis

There are important uncertainties at every stage of the impact-pathway approach. As far as possible, these have been taken into account, in either qualitative or quantitative terms in the uncertainty and sensitivity analysis presented in Chapter 5.

Quantification of emissions and concentrations

These uncertainties affect the measures assessed in the review in a variety of ways, in terms of both scale and direction of impact. It is therefore very difficult to present conclusions as to the overall effect of the combined uncertainties. The major effects are therefore highlighted on an individual basis below.

There are three elements that contribute the greatest uncertainty to the main conclusions drawn in this review for the key pollutants, NO_2, PM_{10} and O_3. These are:

- weather in the future year in question will have a large impact on the extent of exceedences of objectives;
- uncertainties about the response of PM concentrations to changes in emissions of precursor gases; and
- uncertainties about the source apportionment of PM.

These and other uncertainties are discussed in detail in Volume 2 of the Air Quality Strategy.

We are confident that future NO_2 concentrations will exceed objectives in 2010 and 2020, without further measures. The weather in any future year will have an important impact on the extent of exceedences.

For PM_{10}, we are also confident that limited exceedences of the 24-hour objective will still exist near busy roads in 2010 and 2020 but that the annual mean 2004 objective will continue to be attained nearly everywhere.

There is a risk that the effectiveness of measures to mitigate PM_{10} concentrations in the baseline and additional measures will be lower than estimated. Consequently there is a real risk that future concentrations of PM_{10} will be higher than forecast. This is because of uncertainties about (1) the composition of the atmosphere in the future and the responsiveness of PM concentrations to changes in precursor gas emissions; and (2) apportionment of sources of PM. This is potentially important because of the influence that changes to population-weighted concentrations have on estimates of health impacts in Chapter 3.

For ozone, we are confident there will be extensive exceedences of the objective in future years. Measurements show background ozone levels are slowly increasing and that measures to reduce NO_X emissions will increase ozone concentrations in urban areas. Consequently there is a large margin for error in the assessment of future concentrations and we are confident that ozone concentrations will exceed the objective in 2010 and 2020.

Quantification and valuation of benefits

In terms of the uncertainties surrounding the benefits assessment, it has been possible to quantify the scale of the following uncertainties:

- *No long term effect of particles:* It is possible that some unknown confounders could account for the apparent effect of long term exposure to particles on mortality. This is becoming increasingly unlikely as a wider range of studies of the effect of long term exposure to particles is published. Nonetheless, this unlikely possibility has been considered as part of the sensitivity analysis to illustrate that some effects on mortality would still be quantified. The assumption that there are no chronic mortality effects from particles has a major impact on the cost benefit results. For all measures, except Measure E (LEVs) and N (Shipping), the annual net present value is negative i.e. the measures are no longer justifiable in cost benefit terms. Even the shipping measure is only marginally beneficial (annual NPV from £1-5m).
- *Other coefficients for long term effect of particles, in addition to the hazard rates considered in the main analysis:* The recent COMEAP report (Department of Health, 2007), has suggested 'typical low' and 'typical high' sensitivities of a 0.1% and 1.2% hazard rate reduction per µg.m^{-3} $PM_{2.5}$ with 0.6% the most likely. These alternative reductions in hazard rate per µg.m^{-3} $PM_{2.5}$ change the chronic mortality benefits in a linear manner i.e. the chronic mortality values are twice as large when assuming a 1.2% hazard rate reduction per µg.m^{-3} $PM_{2.5}$ as the values when assuming a 0.6% per µg.m^{-3} hazard rate reduction and a sixth smaller when using a 0.1% hazard rate reduction. Table 5.1b uses more complex equations for sensitivity analysis where hazard rate reductions are assumed to be non-linear. For Measures A2 (Euro revised), C2 (Early Euro revised), B (Euro high), H1, H2 and H3 (Retrofit) and K1 (LCP), the lower bound of the NPV using the 0.6% hazard rate reduction is negative but switches to positive using the 1.2% hazard rate reduction. For Measures G1 and G2 (LEZ), I (Domcom coal), and K2 (LCP), the upper bound of NPV becomes positive, although the lower bound remains negative. For all other measures, the effect is not so great as to switch any of the overall net present values i.e. the NPV that were previously negative using the 0.6% hazard rate, remain negative using the 1.2% hazard rate. For Measures A, C, O, P, Q and R, the NPV switches from positive using the 0.6% hazard rate reduction to negative using the 0.1% hazard rate reduction. For Measures A, A2, B, C, C2, H2, H3, K1, O, P, Q and R the upper bound of the NPV using the 0.6% hazard rate reduction is positive but switches to negative using the 0.1% hazard rate reduction. For measure L, the lower bound of the NPV switches from positive to negative but the upper bound remains positive. For all other measures, the NPV (either positive or negative) remains unchanged.
- *Lack of an effect of secondary particles:* The cohort study used to derive the percentage hazard rate reductions found associations with both the $PM_{2.5}$ mixture in general and with sulphates specifically. Nonetheless, there is a view, particularly from toxicology studies, that within the general $PM_{2.5}$ mixture, primary particles are relatively more toxic (per µg.m^{-3}), and secondary particles (sulphates, nitrates) relatively less toxic, than the mixture as a whole. A sensitivity analysis has therefore been performed on the combined Measures O, P, Q and R to disaggregate the overall $PM_{2.5}$ mixture. The same hazard rate has been used for each of the three fractions (primary particles, sulphates, nitrates); i.e. the analysis does not try to

quantify different toxicities for these fractions. The results for O, P and Q show that sulphates make the smallest contribution of the three categories (none for Measure O which is a combination of transport measures only). For these measures, nitrates contribute about half of the life years contributed by primary particles. Thus, for these measures, primary particles are providing the highest proportion of the impact and the proportion would be even higher if it were the case that primary particles were more toxic. Thus, for the combined measures O, P and Q, this sensitivity analysis suggests that the absence of an effect of secondary particles would be unlikely to cause a substantial underestimate of the benefits. For R, primary and secondary particles are contributing approximately equal numbers of life-years – if primary particles are more toxic and secondary particles less toxic, then the net result would probably still be similar to the result assuming all particles have similar toxicity.

- *Inclusion of sequential concentration changes:* The main analysis uses a simplified concentration change scenario where, for the long term measures, the 2020 concentration reduction was assumed to apply from 2010 for 100 years. In fact, the true situation is more complicated. There is a baseline (agreed measures) that itself includes several stepwise concentration reductions starting from 2005. The additional measures also contain stepwise concentration reductions. When these results are compared with each other, using a 0.6% per µg.m^{-3} hazard rate reduction, analysis shows that for the long term measures, the simplified concentration change method used in the main analysis, overestimates the health impacts somewhat. The overestimate increases with increasing size of hazard rate reduction up to a maximum of 11% (no lag) or 20% (40 year lag) for Measure B (the measure resulting in the largest concentration reduction).
- *Shorter lag times between exposure and effect:* The main analysis uses a range in lag times between 0 and 40 years. The 2006 COMEAP statement indicates that, although evidence was limited, the Committee's judgement tended towards a greater proportion of the effect occurring in the years soon after a pollution reduction rather than later. This would mean the effect is more likely to be nearer the no lag result i.e. larger. The no lag result is approximately twice as large as the 40 year lag result so an emphasis on shorter lag times can have a marked effect on the results. Focusing on the net present value results assuming a 0.6% per µg.m^{-3} hazard rate, Measures A2 (Euro revised), B (Euro high), C2 (Early Euro revised), and H2 and H3 (retrofit) have a negative NPV assuming a 40 year lag, but a positive NPV assuming a zero year lag. Therefore, taking account of the Committee's recent views on the lag effect might alter the conclusions drawn.
- *Inclusion of trans-boundary effects:* The main analysis takes account of benefits to the UK from the implementation of measures in the UK and, for Europe-wide measures, from the implementation of measures in other Member States. It does not, however, take account of benefits in the rest of Europe in the form of transboundary effects from the UK. A sensitivity analysis has been undertaken on Measure Q which shows that including such trans-boundary effects would increase the economic benefits by more than 30% over and above the UK benefits alone (given the 100% precursor to secondary particle response function). While the impact of other measures might vary, this suggests that the inclusion of this effect could have a significant impact on the estimate of benefits.

Other areas of uncertainty that have been considered and would increase the benefits (but cannot be quantified with any certainty) include incorporating possible chronic morbidity effects, the inclusion of infant mortality, the inclusion of more minor effects in larger numbers of people (e.g. respiratory symptoms) and the inclusion of the effects of other pollutants such as nitrogen dioxide. All of these possible additional benefits are, however, considered to be small relative to the effect of particles on life expectancy.

Assuming the existence of an 'exposure window' for long term effects of particles (rather than exposure having an effect throughout life) could decrease the benefits substantially but there is insufficient evidence to judge the likelihood of this. Including the possible long term effect of ozone would also have the effect of decreasing the benefits estimates for many policies (as ozone concentrations are increased) but the evidence for a long term effect of ozone is weak compared with the evidence on particles. Considering hospital admissions as brought forward rather than additional would also decrease the benefits but only by a small amount.

Costs

There is considerable uncertainty surrounding the cost estimates. In the recent Evaluation study,[14] it was found that, in the majority of cases, actual 'ex-post' costs associated with the implementation of air quality policies, were lower than 'ex-ante' costs that had been predicted prior to implementation. This would suggest that regulation can spur innovation, and that the ex-ante CBA may not adequately predict the impact of innovation on costs.

For some measures, a range has been used reflecting different underlying assumptions about the costs and they are presented in the central analysis. Sensitivity analysis has been conducted on the cost estimates of specific measures to reflect uncertainties such as the:

- Impact of technological advances on specific technologies used in the measures;
- Impact of considering different implementation options for different measures and the level of take-up of the measures if the measure is a voluntary one; and
- Impact of using different technologies or alternative life spans of the same technology to achieve the required emission reductions.

Some key messages may be drawn from the sensitivity analysis of costs of the measures:

- The costs of the transport measures (Measures A – H) are primarily driven by the resource costs of technology used. Past evidence from the Evaluation study points towards an overestimation of the costs due to the fact that innovation and mass production of the technology used may lead to a substantial fall in costs. A large proportion of the costs Measures A (Euro low), A2 (Euro revised), B (Euro high), C (Early Euro low) and C2 (Early Euro revised) are technology costs and therefore a fall in technology costs could affect these measures considerably. The costs of Measure E (LEV) are also highly uncertain as the NPV 'switches' from positive to negative when more stringent assumptions regarding costs are used.

[14] 'An Evaluation of the Air Quality Strategy' Defra, (2005a).
Available at http://www.defra.gov.uk/environment/airquality/strategy/evaluation/report-index.htm

- For the other measures, uncertainty regarding the costs of the measure depends on the implementation route, the number of plants/firms taking up the option, the lifetime of technology and incorporating fuel efficiency gains. However specific sensitivity analysis conducted on Measures M (VOCs) and N (Shipping) does not show any noticeable changes in the results of these measures.

Monte-Carlo Analysis

A key extension to the IGCB methodology is the application of Monte Carlo analysis. A summary of this work can be seen in Chapter 5.6 and with the full analysis presented in Annex 7 of this report. The use of Monte-Carlo analysis allows us to determine with greater clarity the distribution of the costs and benefits of different measures. The key parameters that are investigated using the Monte-Carlo modelling are:

- The relative risk coefficient for chronic mortality;
- Valuation of mortality;
- Uncertainty over costs;
- Lag phase for chronic mortality;
- Discount rate;
- Costs out turn (ex ante vs. ex post out-turn)

The methodology behind the analysis was presented to the IGCB in February 2007 and comments on the original paper have been incorporated into this report. The valuations that are determined are evaluated using the @RISK econometric software. This type of analysis is likely to be applied in future work by the IGCB.

Conclusions

The analysis presented in this report builds upon the ongoing programme of research undertaken by the IGCB. Further recommendations for future work have been identified and are highlighted in Chapter 6.

The main aim of this report is to present the full evidence, incorporating all the assessments, with regards to the measures under review. A summary of all assessments for each of the measures is presented in Table E.2 below.

Table E.2: Summary of the assessments for AQS review additional measures

Measure	NPV £million	Exceedence assessment	Ecosystem assessment	Major qualitative impacts affecting NPV
Measure A (Euro low)	80 – 801	Between 44% and 100% reduction for individual objectives	Significant positive impact	SI+
Measure A2 (Euro revised)	(264) – 539	Between 46% and 100% reduction for individual objectives	Significant positive impact	SI+
Measure B (Euro high)	(432) – 514	Between 62% and 100 % reduction for individual objectives	Significant positive impact	SI+
Measure C (Early Euro low)	148 – 947	Between 47% and 100% reduction for individual objectives	Significant positive impact	SI+
Measure C2 (Early Euro revised)	(246) – 595	Between 48% and 100% reduction for individual objectives	Significant positive impact	SI+
Measure D1 (Phase out)	(4) – (3)	Not modelled	No/insignificant effects	SI+, N+, H+
Measure D2 (Phase out)	(97) – (93)	Between 0.4% and 5% reduction for individual objectives	No/insignificant effects	SI+, N+, H+
Measure E (LEV)	63 – 112	Between 3% and 9% reduction for individual objectives	No/insignificant effects	SI+, N+
Measure F (Road Pricing)	–	Between 3% and 67% reduction for individual objectives	No/insignificant effects	SI+, N+
Measure G1 (LEZs, London Phase I)	(33) – (1)	Not modelled	No/insignificant effects	SI+, N+, C–, SB–

Table E.2: Summary of the assessments for AQS review additional measures *(continued)*

Measure	NPV £million	Exceedence assessment	Ecosystem assessment	Major qualitative impacts affecting NPV
Measure G2 (LEZs, London Phase II)	(67) – (2)	Between 0% and 33% reduction for individual objectives	No/insignificant effects	SI+, N+, C–, SB–
Measure G3 (LEZs, 7 other urban areas)	(14) – (12)		No/insignificant effects	SI+, N+, C–, SB–
Measure H1 (Retrofit – 65%)	(33) – (17)	Not modelled	No/insignificant effects	SI+
Measure H2 (Retrofit – 20%)	(5) – 0	Not modelled	No/insignificant effects	SI+
Measure H3 (Retrofit – 35%)	(7) – 2	Not modelled	No/insignificant effects	SI+
Measure I (Domcom Coal)	(23) – (15)	Not modelled	No/insignificant effects	SI+, C–, SB–, H+
Measure J (Domcom NOx)	(179) – (148)	Between 0% and 5% reduction for individual objectives	No/insignificant effects	SI+
Measure K1 (LCP)	(107) – 34	Not modelled	No/insignificant effects	C–
Measure K2 (LCP)	(232) – (139)	Between 0% and 15% reduction for individual objectives	Significant positive impact	C–
Measure L (SCP)	18 – 57	Between 0% and 8% reduction for individual objectives	No/insignificant effects	SI+, SB–
Measure M (VOCs)	(249) – (248)	Not modelled	No/insignificant effects	
Measure N (Shipping)	245 – 576	Between 1% and 38% reduction for individual objectives	Significant positive impact	
Measure O (Early Euro low + LEV)	186 – 978	Between 50% and 100% reduction for individual objectives	Significant positive impact	SI+, N+

Table E.2: Summary of the assessments for AQS review additional measures *(continued)*

Measure	NPV £million	Exceedence assessment	Ecosystem assessment	Major qualitative impacts affecting NPV
Measure P (Early Euro low + SCP)	163 – 1,000	Between 52% and 100% reduction for individual objectives	Significant positive impact	SI+, SB–
Measure Q (Early Euro low + LEV + SCP)	203 – 1,053	Between 52% and 100% reduction for individual objectives	Significant positive impact	SI+, N+, SB–
Measure R (Early Euro revised + LEV + Shipping)	33 – 1,211	Between 56% and 100% reduction for individual objectives	Significant positive impact	SI+, N+

Notes:

[a] This summary shows the lowest and highest expected impact by 2020 (2010 for Measures D and G) on baseline exceedences across all objectives and does not represent a range for individual objectives.

SI represent social impacts which includes impacts on distribution, SI+ implies that the measure has a positive impact on distribution, SI- implies a negative impact.

N represents the impacts on noise, N+ implies a positive impact on noise, N- implies that the measure has a negative noise impact, i.e. due to the measure noise increases.

C represents impacts on competitiveness, C+ implies a positive impact and C– represents a possible negative impact

SB represents impacts on small businesses, SB+ implies a positive impact and SB- represents a possible negative impact

H represents qualitative description of the other health impacts these measures may generate, H+ implies a positive health impact. H– implies a possible negative health impact.

1.1 Aims of the report

1. The main aim of this report is to present the economic evidence that has been undertaken to support the production of the revised Air Quality Strategy (AQS). This report accompanies the Air Quality Strategy and related documents[1] and cross refers where appropriate. It focuses primarily on the detailed economic analysis in relation to the selection of potential policy measures.

2. The evidence presented in this report includes an update of the analysis presented in the third IGCB report published alongside the Air Quality Strategy Review.[2] The changes in the evidence base reflect any additional or updated information since publication, responses to the consultation, other recent developments and the introduction of the use of Monte Carlo analysis. For clarity changes to the evidence have been highlighted at the beginning of each chapter.

1.2 The revised Air Quality Strategy

3. Alongside this document the revised Air Quality Strategy was published following the consideration of consultation responses and other recent developments.[3] This sets out a proposed package of measures, to take forward and improve ambient air quality throughout the UK informed by the results of cost-benefit analyses and non-monetary assessments set out in this report and the accompanying RIA.

4. This strategy replaces the 2000 Air Quality Strategy for England, Scotland, Wales and Northern Ireland[4] and its 2003 Addendum[5] that originally set objectives for reductions in the concentrations of nine major pollutants, to be achieved between 2003 and 2010.

5. The AQS review,[6] published in April 2006, considered the existing objectives and proposed changes to some objectives but its primary focus was to assess the possible impacts of potential future policy measures that could be implemented in order to help achieve the existing objectives.

6. The process for selecting the measures under review is described in more detail in Chapter 3 of the Air Quality Strategy Review consultation document.

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[1] Available from www.defra.gov.uk

[2] 'The Air Quality Strategy for England, Scotland, Wales and Northern Ireland: A Consultation Document on Options for Further Improvement in Air Quality', Defra, (2006a). Available at http://www.defra.gov.uk/environment/airquality/index.htm

[3] Available from www.defra.gov.uk/environment/airquality/strategy/index.htm

[4] 'The Air Quality Strategy for England, Scotland, Wales and Northern Ireland – Working Together for Clean Air', DETR, (2000). Available at http://www.defra.gov.uk/environment/airquality/strategy/

[5] 'The Air Quality Strategy for England, Scotland, Wales and Northern Ireland: Addendum', Defra, (2003). Available at http://www.defra.gov.uk/environment/airquality/strategy/addendum/pdf/aqs_addendum.pdf

[6] 'The Air Quality Strategy for England, Scotland, Wales and Northern Ireland: A Consultation Document on Options for Further Improvement in Air Quality', Defra, (2006a). Available at http://www.defra.gov.uk/environment/airquality/index.htm

1.3 The IGCB – its remit and work

1.3.1 Remit of the IGCB

7. The primary remit of the Interdepartmental Group on Costs and benefits (IGCB) is to provide as comprehensive an assessment as possible of all the relevant costs and benefits associated with measures required to meet current or proposed strategy objectives. The group therefore provides the economic analysis which underpins the AQS.

1.3.2 Previous IGCB reports

8. The IGCB published an interim report in January 1999.[7] This report presented the methodology adopted by the IGCB and preliminary results. It provided an assessment of the additional costs and benefits of the 1997 Strategy objectives and made recommendations as to the further research that was required so that a more detailed economic analysis could be conducted.

9. The second report published in 2001[8] supported the review of the Air Quality Strategy Objectives for Particles. It therefore provided the economic analysis underlying proposals for long term objectives for PM_{10}. Its primary focus was on costs and benefits of additional measures that could impact future concentrations of PM_{10}.

10. The third report was published in 2006 alongside the consultation on the review of the Air Quality Strategy. The analysis presented in this report incorporated a comprehensive monetary valuation of air pollution impacts based on the best available information at that time. This represented a major development in the IGCB methodology as it brought together all the previous IGCB analysis to create and apply a single tool to the monetary evaluation of air quality proposals.

1.3.3 Research undertaken since the second IGCB report

11. Following the interim IGCB Report, a substantial programme of research was put into place. Two key pieces of research have delivered since the second IGCB report:

- Valuation of Health Benefits Associated with Reductions in Air Pollution;
- An Evaluation of the Air Quality Strategy; and
- Monte Carlo analysis undertaken to evaluate multiple uncertainties.

1.3.3.1 Valuation of health benefits

12. In May 2004, Defra published a report 'Valuation of Health Benefits Associated with Reductions in Air Pollution'.[9] This was the culmination of a long term research project that used survey-style contingent valuation methods to elicit a range of monetary values for various key mortality and morbidity benefits. The aim was to use these results to help inform appraisals of air quality impacts.

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7 'An Economic Analysis of the National Air Quality Strategy Objectives – An Interim Report of the Interdepartmental Group on Costs and Benefits', DETR, (1999a).

8 An Economic Analysis to Inform the Review of the Air Quality Strategy Objectives for Particles – A Second Report of the Interdepartmental Group on Costs and Benefits' Defra, (2001).

9 Chilton et al (2004) 'Valuation of Health Benefits Associated with Reductions in Air Pollution'. Available at http://www.defra.gov.uk/environment/airquality/valuation/index.htm

13. Following the publication of this report, an expert workshop on the Valuation of Health Benefits of Reductions in Air Pollution and the Use of Values in Appraisal was held in June 2004. This workshop provided an opportunity to compare the results of the Defra study with relevant economic and epidemiological evidence and explored the possibility of using the results in policy appraisals. A summary of the workshop proceedings can be found at http://www.defra.gov.uk/environment/airquality/valuation/workshop.htm.

14. The recommendations from this workshop informed an IGCB paper that sought to agree the valuation of health benefits in policy appraisal. This IGCB paper can be found in Annex 2. These recommendations were agreed interdepartmentally within Government and therefore form the basis of the appraisal of health benefits by the IGCB. This monetary valuation of health impacts represents a major step-change in the IGCB methodology. Details of the quantification and valuation of health effects are provided in Chapter 2.

1.3.3.2 An Evaluation of the Air Quality Strategy

15. One of the remits of the IGCB is to evaluate existing policies associated with the achievement of the AQS objectives. The IGCB contributed input into the scoping and management of a Defra-sponsored research project that evaluated selected air quality policies, in the road transport and electricity supply industries, from 1990 onwards.[10]

16. The project had three main objectives:

- To assess the cost-effectiveness in achieving air quality improvements of the selected policies;
- To assess the costs and benefits of the selected policies; and
- To evaluate how closely the actual out-turns of policies match the anticipated effect.

17. In addition, analysis was also carried out to review a number of local (urban) transport initiatives and is presented in the accompanying report.[11]

18. The results from the evaluation reports are described in more detail in Technical Annex 1 of the main consultation document. The main conclusions that can be drawn are as follows:

- Policies in both the transport and electricity supply industries have led to major emissions reductions;
- The policies have generated large benefits in reducing the health and environmental impacts;

[10] 'An Evaluation of the Air Quality Strategy' Defra, (2005a). Available at http://www.defra.gov.uk/environment/airquality/strategy/evaluation/report-index.htm

[11] 'An Evaluation of the Air Quality Strategy: Additional analysis: local road transport measures', Defra, (2005b). Available at http://www.defra.gov.uk/environment/airquality/strategy/evaluation/report-index.htm#local

- There are good benefit to cost ratios for the air quality policies that have been implemented in both sectors i.e. when comparing estimated actual benefits from policies against the 'ex post' costs; and
- For many, although not all, policies, the ex-post implementation costs have been less than the predicted costs ex-ante.

19. The findings from the evaluation report have been used to inform the analytical work conducted for the review of the AQS.

1.3.3.3 Monte Carlo analysis

20. Monte Carlo analysis has been employed to focus the cost benefit analysis where the CBA has not been able to provide a definitive answer to whether a measures have benefits greater than costs. This is consistent with the guidance in Treasury Green Book to use Monte Carlo analysis as a method for analysing uncertainty of policies. It has also been done for R – the combination of measures identified in the strategy to be considered further.

21. This modelling was undertaken for two measures:

- Measure B. Euro V and VI high intensity scenario. Long-term; and
- Measure R. A combined measure including measures C2 (Early Euro revised) E (LEV) and N (Shipping).

22. The study focuses on the key parameters that may make a difference to the cost benefit analysis undertaken for the AQSR. These include:

- Relative Risk coefficient for chronic mortality
- Valuation of mortality; and
- Cost uncertainty

23. The results of this analysis have been used to inform the revised Air Quality Strategy and is included in this updated IGCB report.

1.4 Structure of report

24. The structure for the remainder of the report is as follows

- **Chapter 2:** describes the overall approach to policy appraisal and describes the methodology for the monetary cost-benefit analysis in detail;
- **Chapter 3:** provides the results for the cost-benefit analysis for each of the measures. This covers the cost and benefit results for all impacts that can be both quantified and monetised;

- **Chapter 4:** describes the results of the non-monetary assessments carried out for each of the measures. The impacts considered under these assessments include objective exceedences, ecosystem effects, additional health impacts, visibility, noise, the effect of ozone on forests, distributional (social) impacts, acid damage to cultural heritage, material damage from NO_X, crop damage from SO_2 and NO_X, and competition and small business impacts;
- **Chapter 5:** describes the uncertainties surrounding the assessments and presents the results of sensitivity analysis that takes account of some of the uncertainty in quantification and valuation;
- **Chapter 6:** draws the results of Chapters 3-5 together, providing scenario comparisons and conclusions;
- The Annexes provide further information on:

  i. **Annex 1:** List of IGCB members

  ii. **Annex 2:** Valuing the health benefits associated with reductions in air pollution – recommendations for valuation

  iii. **Annex 3:** Damage costs

  iv. **Annex 4:** Comparison of methodology with Clean Air for Europe (CAFE)

  v. **Annex 5:** List of additional measures

  vi. **Annex 6:** Monetary cost-benefit analysis results at devolved administration level

  vii. **Annex 7:** Monte-Carlo Uncertainty Analysis of AQS Measures

  viii. **Annex 8:** Impacts of recent changes in energy projections

Chapter 2: Assessment methodology

KEY UPDATES TO THE CHAPTER

This chapter has been updated to reflect the publication of the (draft) full report from COMEAP on the effects on mortality of long-term exposure to air pollution. Only an interim statement from COMEAP was available when the chapter was first written. The main conclusion on the recommended hazard rate reduction remains unchanged in the full COMEAP report but the full report includes more information on uncertainties. This is described in a new paragraph 150. Small changes to reflect this have also been made at various points in the chapter such as the section on the format for the presentation of the results.

A key change in the estimation of concentrations relates to the formation of secondary particles (sulphates and nitrates). Following recent scientific evidence, it has been concluded that the rate of formation of secondary particles does not follow at the same rate as the increase in their precursors (SO_x and NO_x). The estimation of secondary particle concentrations has been amended accordingly.

Finally, the results presented in section 2.8.2, comparing the impact of the combined package of measures (Measure Q) to the baseline impacts have been updated to reflect the results for the new combined measure R (Early Euro revised + LEV + Shipping) proposed by the new Air Quality Strategy. Further discussion of Measure R can be found in Chapter 3. These results have also been updated to reflect the new views on uncertainties discussed above.

2.1 Introduction

1. There are a number of assessments that have been undertaken in order to analyse the efficacy of the different policy measures.

2. A monetary cost benefit analysis (CBA) forms a major part of the overall appraisal. Impacts, in terms of benefits and costs, have been both quantified and valued and are presented in monetary net benefit terms. This chapter focuses on the methodology that underpins the monetary CBA. Chapter 3 then presents the results of the monetary CBA on a measure-by-measure basis.

3. Additional impacts, beyond those captured in the monetary cost benefit analysis, have also been taken into account, including:

   - Exceedences: the impact of policy measures on the existing AQS objectives. This assessment focuses on the potential for measures to improve air quality at current hotspots;
   - Ecosystems: for certain measures, the effects on ecosystems have been quantified. However, it is not possible to put a monetary value on these effects and they are therefore presented in terms of the effect on critical load exceedences; and
   - Qualitative assessments: for some impacts, the uncertainty surrounding the effect of measures is so great that it is impossible to quantify them. In these instances, only a qualitative assessment has been included, providing some indication as to the direction and scale of the effect on the associated outcome. The qualitative

assessments that have been considered include the impact on additional health outcomes, visibility, noise levels, ozone damage to forests, distributional impacts, damage to cultural heritage, material damage from NO_X, crop damage from SO_2 and NO_X and competition and small business impacts.

4. The methodology and results for the additional impacts outlined in paragraph 3 are described in Chapter 4 of this report. It should be noted that all impacts, not only those that form part of the monetary CBA, should be taken into account when assessing the relative merit of the measures.

2.2 Choice of measures for assessment within the AQS review

5. The process of choosing the measres that were assessed in the Air Quality Strategy review (AQSR) are described in section 3.1.1 of Chapter 3 of the AQSR consultation document. In summary, a range of potential measures were analysed using a preliminary cost-effectiveness assessment undertaken by the IGCB. The decision on the shortlist of measures that was taken forward for full assessment was then made in conjunction with both internal and external stakeholders, using this preliminary assessment as input.

6. The measures that were chosen for assessment are described in summary in the Executive Summary and in more detail in Annex 5. The detailed assumptions for each measure are described in Chapter 3 of this report.

7. In addition to the measures directly assessed in the AQSR, evidence has also been drawn from other sources e.g. from the Evaluation of the AQS report[1] and work by other government departments conducted as part of the Climate Change Programme Review.

2.3 CBA methodology

8. This section provides an overview of the methodology used for the monetary cost benefit analysis.

9. CBA provides a framework to compare different policies. In its simplest form, the costs and benefits of each policy are quantified and valued in monetary terms. The costs are subtracted from the benefits and those policies with the higher net benefit are considered preferable to those with a lower net benefit. In practice, undertaking a CBA of policies related to air quality involves considerable complexity and uncertainty and there are a number of possible methodological approaches.[2]

10. Cost benefit analysis has the advantage of presenting costs and benefits in the same metric i.e. money. It therefore facilitates comparison both of differing impacts within the same measure (e.g. the effects of different pollutants), and of differing air quality

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[1] 'An Evaluation of the Air Quality Strategy', Defra, (2005a). Available at http://www.defra.gov.uk/environment/airquality/publications/stratevaluation/index.htm

[2] The remainder of this chapter describes the IGCB CBA methodology. Annex 4 provides a brief comparison with the CBA methodology underpinning the Clean Air For Europe analysis.

measures themselves. In a broader context, the monetary cost benefit results from air quality measures can also be compared with the CBA of measures in other policy areas to assess where limited resources can best be used.

11. In previous work by the IGCB, the analysis stopped short of presenting the benefits in monetary terms. As described in Chapter 1, however, values for health effects have now been agreed and are incorporated into the analysis supporting the new AQS. This enables a partial monetary CBA to be presented for each of the measures.

12. It should be noted that not all costs and benefits can be monetised and therefore the monetary CBA does not present the full picture. In addition, there are considerable uncertainties surrounding both the quantification and valuation of costs and benefits and these need to be taken into account when interpreting the CBA results. These uncertainties are explored in more detail in Chapter 5 of this report.

2.3.1 The impact-pathway approach

13. The CBA of air quality measures presented in this report adopts the impact-pathway approach. The main steps are outlined below and are discussed in more detail in the remainder of this chapter:

- Quantification of emissions for both the baseline and additional policy measures;
- Conversion of projected emissions into population weighted concentrations for the baseline and differing policy scenarios. This is used to quantify the exposure of people, the environment and building to changes in air quality;
- Quantification of health and non-health impacts associated with the change in pollutants, for example, using concentration-response functions that estimate the relationship between changes in air pollutants and changes in health outcomes;
- Valuation (monetisation) of health and non-health impacts;
- Assessment of costs associated with the implementation of each of the policy scenarios;
- Comparison of costs and benefits on a consistent basis; and
- Description and analysis of uncertainties associated with the quantification and valuation of impacts.

14. A large volume of information is therefore required in order to undertake the CBA. This chapter aims to describe the sources of the information underpinning the analysis, as well as highlighting the uncertainties surrounding each step in the process.

15. Following the full impact-pathway process in its entirety is resource intensive. Therefore, for a number of policies, the benefits have been assessed on the basis of emissions only. Estimates of the health impacts and monetary values per tonne of pollutant have been applied to the projected emissions for these scenarios, using different estimates for different sectors. These estimates are themselves derived using the impact-pathway approach; a description of the derivation of these per tonne estimates is provided in section 2.5.6 of this Chapter.

2.3.2 Assessing the measures on a consistent basis

16. Each policy measure needs to be analysed on a consistent basis to enable accurate policy recommendations to be made between different policies. All policy measures have been assessed against a counterfactual that takes account of what would have happened 'anyway'. This is described as the baseline. The baseline takes account of the expected changes in air pollution as a result of current policies and agreed and planned future polices, such as the implementation of the Large Combustion Plant Directive and European directives on vehicle emissions and fuel quality. The baseline is described in section 2.4 of this chapter.

17. Another issue that arises is whether or not £1 that accrues in the future should be valued the same as £1 that accrues in the current year. In economic terms, future flows of cash are assumed to be worth less than current flows of cash due to the social rate of time preference i.e. the fact that people would prefer cash now rather than in the future and attach a greater value to present consumption as opposed to future consumption. Future costs and benefits have therefore been discounted, using 2005 as a base year, in line with current HM Treasury Green Book recommendations. These recommendations are: a discount rate of 3.5% for the first 30 years, 3.0% for years 31-75 and 2.5% for years 76-125.

18. The policies being assessed have differing timescales. Some are being assessed over a 100 year period, while others are being assessed over only a 5 or 10 year period. In order to ensure consistency of comparison between differing timeframes associated with the different policy measures, all costs and benefits are presented on an annualised basis.

2.3.3 Uncertainties

19. There are uncertainties associated with every stage of the impact pathway approach described above. The major areas of uncertainty include:

- Uncertainties in the modelling of the baseline: for example the effect of different meteorology. These are highlighted in section 2.4 of this chapter and discussed in more detail in Chapter 5;
- Uncertainties surrounding the impact of technologies that are assumed in the additional measures: The analysis takes account of best available information regarding the potential impact of different technologies on emissions. Sensitivity analysis exploring the uncertainty regarding the relationship between emissions and population weighted concentrations is discussed in Technical Annex 2 of the AQSR consultation document;
- Uncertainties surrounding the health and non-health impacts of changes in air quality: Different assumptions regarding lag effects for chronic mortality are included in the central analysis shown in Chapter 3 of this report and summarised in the evidence base (Volume 2) published with the new AQS. Chapter 5 explores alternative assumptions and uncertainties surrounding the quantification of health impacts, including the new recommended sensitivities for hazard rates in assessment

on chronic mortality effects[3]. Chapter 4 discusses additional health benefits for which there is clear evidence linking the pollutant to the health outcome but for which quantification was not possible for one reason or another;

- Uncertainties in the valuation of health impacts: The central analysis uses the central values as recommended in the valuation paper in Annex 2. Sensitivity analysis using the recommended ranges is shown in Chapter 5; and
- Uncertainties in the costs: Innovation and structural changes within the economy may both impact future costs. For some measures, a range of costs has been used to reflect some of this uncertainty. In most instances, however, it is impossible to predict such changes with any accuracy and therefore the central analysis uses current best estimates for costs. The impact of changing costs on the net benefit results is discussed in Chapter 5.

20. All of these uncertainties are outlined in the relevant sections within the remainder of this chapter and discussed in more detail in Chapter 5 of this report. Many of these uncertainties are also assessed as part of the new Monte Carlo analysis carried out for selected measures considered by this report. The headline methodology and results of this analysis can be found in section 5.6 of Chapter 5. However, even with the additional sensitivity analysis and Monte Carlo analysis, it is still only possible to account for some, and not all, of the inherent uncertainty within this analysis and the results should therefore be interpreted in this context.

2.4 Quantification of emissions and population weighted concentrations

2.4.1 Assessing current and future air quality

2.4.1.1 Current air quality

21. Current air quality is assessed using a combination of measurement and modelling. Defra and the devolved administrations manage a national network of air quality monitoring sites that measure concentrations of air pollutants. Measurements from these sites are published at www.airquality.co.uk.

22. It is impossible to measure air quality everywhere, so the measurement network is supplemented by national air quality modelling. This estimates concentrations of air pollutants nearly everywhere in the United Kingdom, with the exception of non-urban roads. We supplement the national air quality model with additional specific modelling for London, Glasgow, Cardiff and Belfast, using a different type of model, ADMS-Urban. We also model impacts of air pollution on ecosystems on a national basis. The combination of measurement and modelling provides a comprehensive assessment of the current and historic air quality in the United Kingdom. Figure 2.1 presents a highly simplified summary of the process of modelling air quality.

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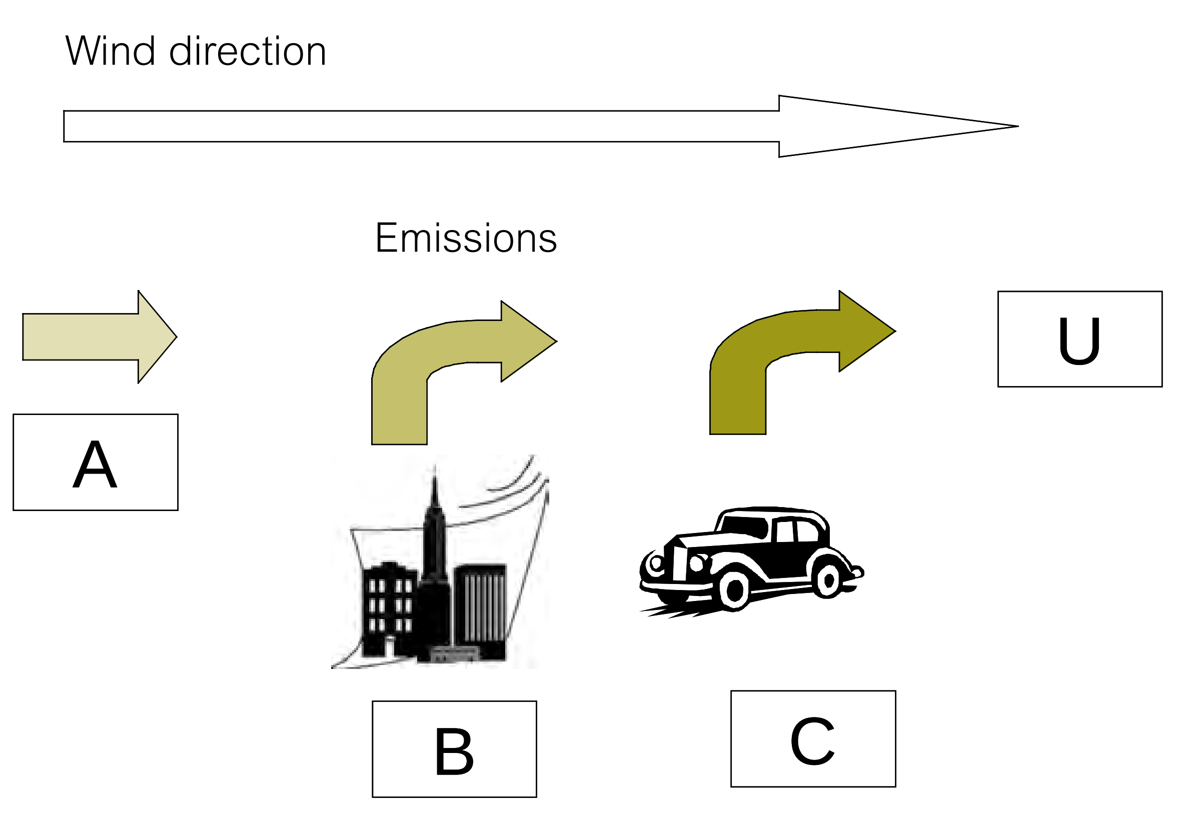
[3] As recommended by the Department of Health's Committee on the Medical Effects of Air Pollutants (Department of Health, 2007). Available at http://www.advisorybodies.doh.gov.uk/comeap

Figure 2.1



23. Air quality models aim to estimate the concentration of a pollutant at point or area U (for example, an urban background location within the vicinity of a busy road). In other words, what would an air quality instrument measure if located there?

24. Most models attempt to predict the concentration of a pollutant at point or area U using information or assumptions about:

- concentration of the pollutant outside the urban area (A);
- emissions of the pollutant from all the sources in the urban area (B);
- emissions from the road traffic near to U (C); and
- meteorological conditions.

25. Although this appears relatively straight forward, it is actually a challenging and complex process because of the complexity of chemical reactions and physical processes in the atmosphere and the diversity and complexity of pollutant emissions sources and emissions rates. It is not practically possible to measure actual emissions from all sources. These are also estimated and consequently comprise an important uncertainty in the modelling process.

26. Models range in complexity from relatively simple statistical models to highly complex models. The relatively simple statistical models calculate a relationship between measured concentrations and pollutant emissions and extrapolate this to other locations and into the future, based on estimated emissions. The complex models attempt to recreate mathematically the actual processes of pollutant emission, formation and transport in the atmosphere.

27. A key change in the estimation of concentrations relates to the formation of secondary particles (sulphates and nitrates). Following recent scientific evidence the rate of formation of secondary particles has been shown not to change at the same rate as the increase in their precursors (SO_X and NO_X). Therefore where measures are seen to alter the emissions of SO_X or NO_X the associated change in secondary PM has been adjusted. For the package of measures[4] identified to be considered this adjustment has been made by altering the formation assumptions for the full concentration modelling. However for the measures outside this package the impacts have been adjusted through scaling. More information on the reason for this change in assumption can be found in the Volume 2 released alongside the Air Quality Strategy (2007).

2.4.1.2 Projecting future air quality

28. In addition to assessing current and historic air quality, we need to estimate future air quality. This allows us to predict the impact of current and potential future measures on future air quality.

29. We have used a range of methods to project future air quality, based on estimates of future air pollutant emissions. These involve simple empirical/statistical models, where air quality from low-level sources is assumed to be proportional to emissions rates, to more sophisticated deterministic models in the case of particles, ozone, nitrogen dioxide and sulphur dioxide. Furthermore, a national mapping methodology generates UK-wide maps of annual mean benzene, 1,3-butadiene, nitrogen dioxide, PM_{10} and $PM_{2.5}$ concentrations at background locations for both current and future years. These maps are based on estimates of emissions provided by the National Atmospheric Emissions Inventory (NAEI).[5]

30. A series of reports[6] describes in detail the methodologies for modelling air quality for the review of the AQS.

31. Section 2.4.2 discusses the methodology for emission projections used to calculate the predictions of future air quality.

32. There are currently no limit values or objectives for $PM_{2.5}$. It is however possible that targets may be set in the future and we have assessed concentrations during 2003 and baseline projections for future years.

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4 Measure R; changed formation assumptions for full concentration modelling were also applied to A2 and C2.

5 See website www.naei.org.uk

6 Stedman et al (2006) 'Projections of Air Quality in the UK for Additional Measures Scenarios for the 2006 Review of the Air Quality Strategy', National Atmospheric Emissions Inventory, AEA Technology, National Environmental Technology Centre. Report AEAT/ENV/R/1986. Grice et al (2006) 'Baseline Projections of Air Quality in the UK for the 2006 Review of the Air Quality Strategy', National Atmospheric Emissions Inventory, AEA Technology, National Environmental Technology Centre. Report AEAT/ENV/R/1936.

33. Separate reports describe in detail the assessments of the future concentrations of ozone[7] and polycyclic aromatic hydrocarbons.[8] There were no measured exceedences of the AQS objectives (0.5 and 0.25μg.m^{-3} annual mean) or the limit value (0.5μg.m^{-3} annual mean) for lead in 2003. We do not expect emissions to increase so future exceedences are highly unlikely. No further analysis has been undertaken.

34. Modelled data for NO_2 and PM_{10} are also presented as population weighted annual means. These represent the average concentration exposure of the UK population and can be used to calculate the health impacts and expected health benefits resulting from reductions in ambient concentrations.

35. Baseline projections for the AQS review are described by Grice et al (2006) and scenarios projections are described by Stedman et al (2006).

2.4.1.3 Why use maps of air quality?

36. Mapping current and future pollutant concentrations across the UK involves the estimation of concentrations at geographic points for which there is no ambient monitoring data. Mapping therefore introduces additional uncertainties when compared to analysis conducted at sites for which there is ambient monitoring data. Nevertheless, maps produce additional information that cannot be derived from analysis of ambient monitoring data alone. In particular they allow the estimation of:

- the extent of exceedences of AQS objectives in urban background, roadside or industrially influenced locations where there is no monitoring data;
- when combined with the appropriate dose-response relationships, health and non-health impacts across the UK, associated with current and future pollutant concentrations expected on the basis of existing national policy measures; and
- a proportion of the additional health and non-health benefits that might accrue across the UK as a result of further reductions in pollutant emissions.

2.4.2 Emissions

37. The Air Quality Strategy (2000) describes the approach to estimating future emissions of air pollutants. The baseline projections used here are described in detail in Hobson (2005),[9] Vincent et al (2005),[10] and Vincent (2005).[11] The current emission projections are based on Department of Trade and Industry's UEP12 energy forecasts,[12,13]

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[7] Hayman et al (2005) 'Modelling of Tropospheric Ozone', AEA Technology, National Environmental Technology Centre.Report AEAT/ENV/R/1858

[8] Vincent K J (2005) 'Assessment of Benzo[a]pyrene Concentrations in the United Kingdom in 2003', AEA Technology, National Environmental Technology Centre. Report AEAT/ENV/R/1861

[9] Hobson, M (2006) 'Emission Projections', AEA Technology, National Environmental Technology Centre

[10] Vincent K J and Passant N (2005) 'Assessment of Heavy Metal Concentrations in the United Kingdom', AEA Technology, National Environmental Technology Centre. Report AEAT/ENV/R/2013

[11] Vincent K J (2005) 'Assessment of Benzo[a]pyrene Concentrations in the United Kingdom in 2003', AEA Technology, National Environmental Technology Centre. Report AEAT/ENV/R/1861

[12] Department of Trade and Industry updated emissions projections. Final projections to inform the National Allocation Plan (NAP) 11 November 2004. Available at http://www.dti.gov.uk/energy/sepn/uep2004.pdf ?pubpdfdload=04%2F2099

[13] During the course of this evaluation subsequent DTI forecasts were been released, in UEP21 and UEP26. While such changes will alter the estimated concentrations they have a negligible effect on the marginal impact of the measures appraised within this document. This information is presented in Volume 2 Chapter 1 of the evidence base published alongside the Air Quality Strategy. Information on the monetary impacts of altering the energy projections are provided in Annex 8 of this report.

Department for Transport's 10 year plan for transport,[14] updated in September 2004,[15] and the 2002 National Atmospheric Emissions Inventory (NAEI).[16]

38. The general principle has been to embody in the projections those policies or commitments that are already in place or those on which agreement has been reached, even if the full administrative and legal procedures have not been finalised.

39. Regulations that have been taken into account include:

- The large combustion plant Directive (LCPD);[17]
- IPPC Directive;[18]
- The Solvent Emissions Directive;
- Marpol VI;[19]
- Sulphur content of liquid fuels regulations; and
- European directives on vehicle emissions and fuel quality.

40. The baseline projections assume that all relevant measures continue to be implemented and enforced, and all calculations and estimates are based on this. Progress on vehicle emissions, for example, is dependent upon the MOT system continuing to effectively monitor and regulate vehicle emissions. Forward thinking on particulates pre-supposes that the Clean Air Act controls on domestic premises will continue in force. The projections also assume that emissions reductions achieved through the Pollution Prevention and Control legislation and predecessor regimes continue to be delivered and enforced by the Environment Agency and local authorities.

2.4.2.1 Road traffic emissions forecasts

41. Motor vehicles are the major contributor to ground level concentrations in urban areas for most of the pollutants covered by the Strategy. The projection of future emissions from this sector is therefore central to estimating future air quality. The projections for this work were carried out by Netcen using the road traffic emissions factors and methods incorporated in the National Atmospheric Emissions Inventory (NAEI). Full details of the methods and factors are available.[20]

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[14] 'Transport Ten Year Plan 2000', Department for Transport (2000). Available at http://www.dft.gov.uk/stellent/groups/dft_about/documents/page/dft_about_503944.hcsp

[15] 'The Future of Transport – White Paper', Department for Transport, (2004b). Available at http://www.dft.gov.uk/stellent/groups/dft_about/documents/divisionhomepage/031259.hcsp

[16] Available at http://www.naei.org.uk/reports.php.

[17] The Government has not taken final decisions on the implementation route in the UK. The UEP12 projections are broadly consistent with an emissions limit value approach.

[18] The Integrated Pollution Prevention and Control Directive aims to minimising pollution from various point sources throughout the European Union. All installations covered by the Directive are required to obtain an authorisation (permit) from the authorities in the EU countries

[19] An international agreement under the UN for limiting air pollution by ships. From 19th May 2005 the fuel used must contain no more than 4.5 per cent sulphur.

[20] Grice et al (2006); Stedman et al (2006).

42. The emission projections generally assume that measures are introduced when required by legislation and not earlier and that all processes comply with this legislation.

43. The assumptions behind the activity data in the road transport emission projections contained in the current emission forecasts are as follows:

- Vehicle kilometre estimates by vehicle and area type for current years are based on the Department for Transport (DfT) traffic census and are projected forward in time using vehicle kilometre forecasts from DfT's National Transport Model.[21] Central traffic forecasts from 'The Future of Transport – White Paper'[22] are also used. The DfT figures are for 2010, 2015, 2025 and are interpolated for other years.
- The numbers of vehicles of different ages in the vehicle fleet are calculated using survival rates of the vehicles, modelled in terms of the probability that a vehicle of each different age remains on the road (starting at 1 for 1 year old vehicles, decreasing towards 0 as age increases). The survival rates of different types of vehicles are based on historical trends. The maximum age that a vehicle can remain on the road is assumed to be 20 years. The average vehicle lifetime implied by these survival rates is 12 years for cars, 10 years for LGVs and rigid HGVs and 8 years for articulated HGVs.
- Estimates of new vehicle sales in future years are based on re-scaled forecasts from DfT's Vehicle Market Model.[23] Account is taken of the change in annual mileage with age of vehicle using data from surveys carried out by DfT such as the National Travel Survey[24] so that the proportion of kilometres travelled by vehicles of different age meeting different Euro standards in any one year can be calculated. It is assumed that the growth in the percentage of diesel cars sold continues so that by 2010, 42% of all new cars sold in the UK are diesel.
- In the baseline, it is assumed that no further Euro standards and vehicle technologies beyond those currently legislated are assumed to penetrate the fleet. Standards up to Euro IV for light-duty vehicles and Euro V for heavy-duty vehicles are included and it is assumed that the early introduction of some petrol cars meeting Euro IV standards occurs before the legislated date of 2005.
- Measurements of vehicle emission factors for vehicles meeting Euro III and IV standards (and Euro V for HDVs) are not currently available so are estimated by Netcen taking into account the type approval emission limits and durability requirements of the legislation.
- The penetration of sulphur-free petrol and diesel fuels are mandatory from January 2009 by EU Directive 2003/17/EC and therefore their impact on emissions is assumed in the baseline.

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[21] 'The National Transport Model', Department for Transport (2003). Available at http://www.dft.gov.uk/stellent/groups/dft_econappr/documents/divisionhomepage/030708.hcsp

[22] 'The Future of Transport – White Paper', Department for Transport, (2004b). Available at http://www.dft.gov.uk/stellent/groups/dft_about/documents/divisionhomepage/031259.hcsp

[23] See website http://www.rmd.dft.gov.uk/project.asp?intProjectID=10045

[24] See website http://www.statistics.gov.uk/ssd/surveys/national_travel_survey.asp

- Estimates of the fuel efficiency of current and new vehicles in the fleet are based on figures from DfT, including fleet-averaged estimates for HGVs from the 'Continuous Survey for Road Goods Transport' and figures on the CO_2 emissions (related to fuel efficiency) for new cars from DfT and the Society of Motor Manufacturers and Traders (SMMT). The fuel efficiency of new cars in the future is also based on estimates from DfT/SMMT in anticipation of downward trends in CO_2 emissions from new cars driven by the car manufacturers' Voluntary Agreement.
- Netcen estimates future trends in the fuel efficiency of other vehicle types based on the considered impact of technological changes introduced to meet tighter emission standards on air quality pollutants. Table 2.1 shows the estimated fuel efficiency of new cars and HGVs sold in 2000 and 2010

Table 2.1: Fuel efficiency of new cars and HGVs sold in 2000 and 2010

Vehicle Type	Fuel efficiency (litre/100km)	
	2000	**2010**
Petrol Car	7.9	6.6
Diesel Car	6.3	5.4
Articulated HGV	37.8	36.0
Rigid HGV	28.2	26.9

2.4.3 Results of the baseline assessment

44. The following section summarises the national air quality assessment and projections for the baseline. It highlights which pollutants we judge are meeting air quality objectives and those we judge are not meeting objectives. Full results of the assessment, including measurement data and modelling results, are available in Technical Annex 2 of the consultation document.

2.4.3.1 Air pollutant emissions projections

45. Table 2.2 summarises the latest emissions projections. These projections are the key assumptions that underpin the results of the baseline modelling.

Table 2.2: Total national emissions used for modelling concentrations, kilotonnes[a]

Pollutant	2002	2003	2005	2010	2015	2020
Sulphur dioxide (SO_2, ktonnes)	1,002	*933	795	484	397	360
Nitrogen oxides (NO_X, ktonnes)	1,582	*1,525	1,413	1,119	992	869
PM_{10} (ktonnes)	161	*156	148	134	134	142
$PM_{2.5}$ (ktonnes)	93	*89	81	73	72	75
Benzene (ktonnes)	13.5	*12.8	11.3	10.1	9.9	10.4
1,3-Butadiene (ktonnes)[b]	3.65	n/a	n/a	n/a	n/a	n/a
Carbon monoxide (CO, ktonnes)[b]	3,238	n/a	n/a	n/a	n/a	n/a
Non methane volatile organic compounds (NMVOCs, kilotonnes)	1,186	*1,120	990	848	857	883
Ammonia (NH_3, kilotonnes)	301	*300	298	273	270	270
Lead (tonnes)[b]	162	n/a	n/a	n/a	n/a	n/a
Polycyclic aromatic hydrocarbons (marker B[a]P, tonnes)	9.3	n/a	7.7	7.4	7.5	7.9

[a] Source: Hobson (2006)

[b] No projections have been produced for 1,3-butadiene, CO or lead because objectives are currently being met.

* Values have been interpolated from the 2002 and 2005 emission totals.

Box 2.1 TEOM and Gravimetric Measurements

The reference method for the Air Quality Daughter Directive limit values and AQS objectives for PM_{10} is the use of a gravimetric instrument. All the analyses of particle concentrations presented in this report are based on TEOM (Tapered Element Oscillating Microbalance) or equivalent instruments, which are currently widely used within the UK national monitoring networks. For PM_{10}, a scaling factor of 1.3 has been applied to all data before comparing with the limit value, as suggested by the Airborne Particles Expert Group.[a] This factor was also recommended as an interim measure by the EC Working Group set up to address the issue of scaling automatic PM measurements in advance of Member States undertaking their own detailed intercomparisons with the Directive Reference Method. The UK is currently undertaking such a detailed comparison. The results are due to be published later in 2006. The UK is published such a detailed comparison in June 2006. The results are discussed in Section 1.2.3 of Volume 2 released alongside the new AQS.

Box 2.1 TEOM and Gravimetric Measurements *(continued)*

All PM_{10} concentration data reported within this study are given in units of $\mu g.m^{-3}$, gravimetric, meaning that TEOM data has been scaled by the 1.3 factor to give a representation of concentrations as measured by a gravimetric, or equivalent instrument. A sensitivity analysis for the scaling factor was included in the second report of the IGCB, 'An economic analysis to inform the review of the Air Quality Strategy objective for particles'.[b]

There is currently no agreed scaling factor for $PM_{2.5}$. All $PM_{2.5}$ concentration data – both measured and modelled – within this study are gravimetric.

[a] 'Source Apportionment of Airborne Particles in the UK', Airborne Particles Expert Group, (1999). Available at www.defra.gov.uk/environment/airquality/airbornepm/ap01.pdf

[b] Available at http://www.defra.gov.uk/environment/airquality/publications/particle-objectives/index.htm

Sulphur dioxide (SO_2)

46. SO_2 is mainly emitted as a by-product of fuels containing sulphur. The main source of emissions in the UK is from electricity generation fuelled by coal.

47. We expect emissions of SO_2 particularly from power stations to continue a long term decrease in response to current legislation.

Oxides of nitrogen (NO_X)

48. NO_X is mainly emitted from combustion processes. There are a wide variety of sources of NO_X, with road transport and the electricity supply industry as the main sources.

49. We expect emissions of oxides of nitrogen to continue their long term decline to 2020. The main sectors contributing to this decrease are road transport and electricity generation.

Primary particulate matter (PM_{10} and $PM_{2.5}$)

50. PM_{10} and $PM_{2.5}$ are emitted by a wide variety of sources including road vehicles, domestic heating (coal and wood fuels), quarrying, and other industrial sources.

51. Our latest projections suggest that emissions of primary PM_{10} and $PM_{2.5}$ will continue a long term decline until around 2015, but without further measures may gradually increase after that. This is due to projected increases from quarrying, domestic combustion, cement and construction sectors. Since these projections were carried out, the estimate of emissions from quarrying has been revised downwards but it has not been possible to incorporate this change in the current analysis.Updated projections in 2006 may estimate a continued small decline in primary PM_{10} emissions after 2015. This change is unlikely to alter materially the results of the baseline analysis presented in this document.

Benzene

52. Benzene also has a wide variety of sources, mainly road vehicles, domestic combustion of coal and wood for heating and industrial processes.

53. We expect benzene emissions to continue to decline until around 2015, but without further measures are likely to increase after that. This is due to increases in activity of domestic coal, natural gas and wood burning in the years following 2010. There is also a predicted increase in the activity of the chemical industry in later years.

Non-methane volatile organic compounds (NMVOCs)

54. NMVOCs are emitted mainly from the use of solvents and from industrial processes, as well as fuel combustion. Emissions are expected to decline until 2010 due to the implementation of the Solvents Directive, then are likely to increase due to increases in activity in domestic coal, natural gas and wood burning plus industrial adhesives and other solvent use activity.

Ammonia

55. Ammonia emissions in the UK are almost entirely from agriculture. Emissions are expected to reduce to 2010 and then remain approximately constant.

Polycyclic aromatic hydrocarbons (PAHs)

56. PAH encompasses many substances. In the context of the AQS, benzo[a]pyrene (B[a]P) is used as a marker compound for total PAH emissions. Emissions of B[a]P are expected to decline to 2010 then emissions are likely to increase due to increased activity in the domestic sector for coal, anthracite and solid smokeless fuels.

2.4.3.2 Summary of progress against objectives

57. The following section summarises our assessment of current and future air quality in comparison to the AQS objectives and EU limit values. Details of the assessment are published separately in the Evidence base published alongside this Air Quality Strategy.

58. Baseline impacts on health are presented in section 2.8.2 of this chapter.

59. Figure 2.2 presents a summary of the measured concentrations of AQS pollutants in 2004. The figure shows the measurements from (a) the mean of all sites – the green bars – and (b) the site recording the highest measurement – the vertical green lines. The measurements have been normalised compared to the relevant objective concentration, represented as 100%. This is to enable all pollutants to be shown on one chart. Measurements above the 100% line indicate an exceedence of the relevant objective in 2004.

60. Table 2.3 presents a summary of measures and modelled exceedences of relevant AQS objectives and EU limit values. The projections in the table start from a base year of 2003. 2003 was an unusual year for air quality with higher than recent concentrations of PM_{10} and ozone in some parts of the UK. Projections that start in 2003 will consequently be higher for some areas than projections that start in a year with generally better air quality. While this may have a significant impact on the exceedences it does not have an impact on the estimated benefits from individual policy proposals as they have been evaluated on the basis of marginal changes. The sensitivity of the base year for the projection is explored in Chapter 5 of this document.

Figure 2.2

Measures concentrations of pollutants in the UK in 2004 as a percentage of the relevant objectives (mean of all sites and highest site)

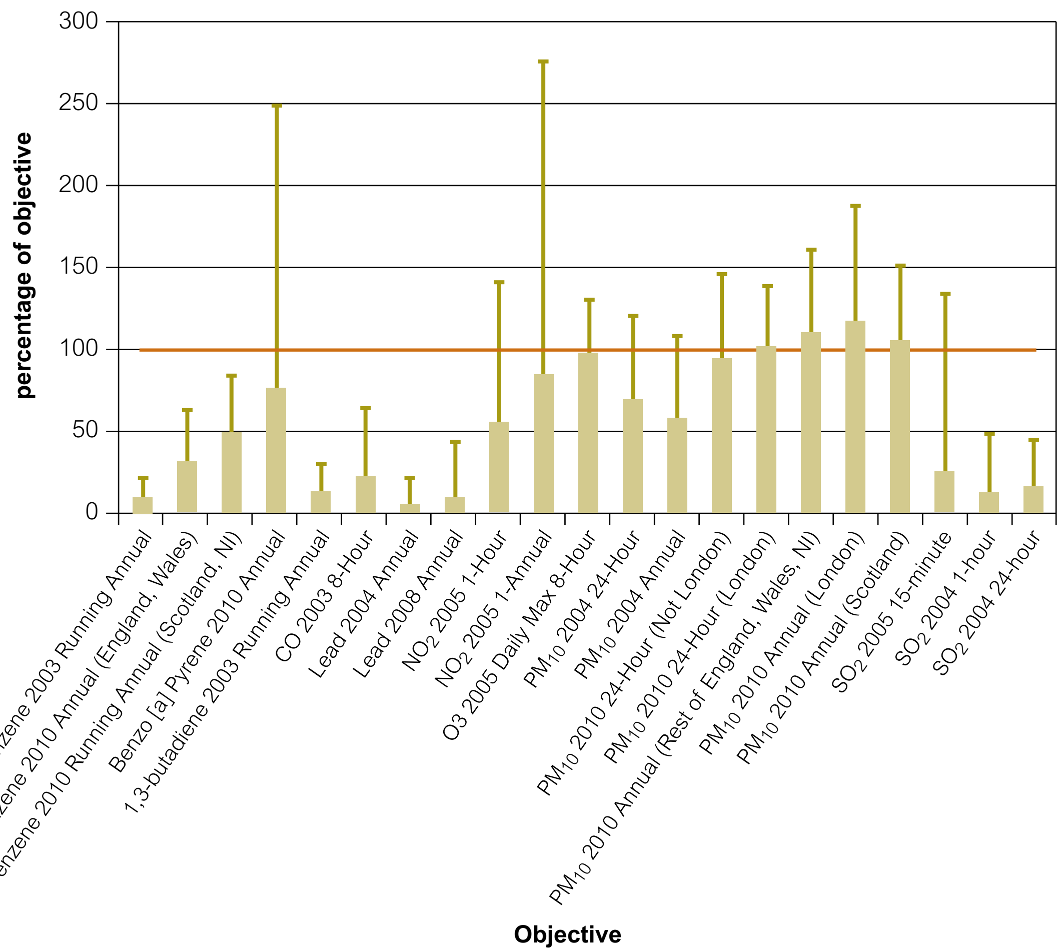

Table 2.3: Summary of modelled total percentage exceedences using a 2003 base year

Percentage of total urban major road length exceeding (%) (total UK road length assessed 14,084 km)						
Pollutant	**Threshold**	**2003**	**2005**	**2010**	**2015**	**2020**
SO_2	15 minute mean limit value	N/A	N/A	N/A	N/A	N/A
	1 hour and 24 hour limit value	N/A	N/A	N/A	N/A	N/A
NO_2	Annual mean >40µg.m^{-3}	52.5	41.3	18.2	10.0	8.5
PM_{10}	Annual mean >31.5µg.m^{-3}	16	10	2	0.5	0.3
	Annual mean >20µg.m^{-3} (rest of England 2010 objective)	98	97	89	76	67
	Annual mean >20µg.m^{-3} (Wales 2010 objective)	94	88	53	30	22
	Annual mean >20µg.m^{-3} (Northern Ireland 2010 objective)	54	36	14	11	14
	Annual mean >18µg.m^{-3} (Scotland 2010 objective)	84	76	49	28	23
	Annual mean >23µg.m^{-3} (London 2010 objective)	100	100	92	87	72
$PM_{2.5}$	Annual mean >20µg.m^{-3}	9.0	4.3	0.2	0.0	0.0
	Annual mean >16µg.m^{-3}	53.1	42.3	10.9	2.3	0.9
	Annual mean >12µg.m^{-3}	85.0	82.7	72.3	58.6	46.7
Benzene	Annual mean > 5µg.m^{-3}	1.0	0.0	N/A	N/A	N/A
CO	8 hour mean > 10mg.m^{-3}	0.0	N/A	N/A	N/A	N/A
1,3-butadiene	Annual mean > 2.25µg.m^{-3}	0.0	N/A	N/A	N/A	N/A
Percentage of total background area exceeding (%) (total UK area assessed 242,248 km^2)						
Pollutant	**Threshold**	**2003**	**2005**	**2010**	**2015**	**2020**
SO_2	15 minute mean limit value	0.65	0.46	0.01	0.01	0.01
	1 hour and 24 hour limit value	0.01	0.01	0.01	0.01	0.01
NO_2	Annual mean >40µg.m^{-3}	0.2	0.1	0.0	0.0	0.0

Table 2.3: Summary of modelled total percentage exceedences using a 2003 base year *(continued)*

Percentage of total background area exceeding (%) (total UK area assessed 242,248 km^2)						
Pollutant	**Threshold**	**2003**	**2005**	**2010**	**2015**	**2020**
PM_{10}	Annual mean >31.5µg.m^{-3}	0	0	0	0	0
	Annual mean >20µg.m-3 (rest of England 2010 objective)	60	50	13	6	4
	Annual mean >20µg.m^{-3} (Wales 2010 objective)	8	5	1	1	1
	Annual mean >20µg.m^{-3} (Northern Ireland 2010 objective)	2	1	1	0.1	1
	Annual mean >18µg.m^{-3} (Scotland 2010 objective)	1	0.6	0.1	0.1	0.1
	Annual mean >23µg.m^{-3} (London 2010 objective)	97	93	35	10	4
Percentage of total urban major road length exceeding (%) (total UK road length assessed 14,084 km)						
Pollutant	**Threshold**	**2003**	**2005**	**2010**	**2015**	**2020**
$PM_{2.5}$	Annual mean >20µg.m^{-3}	0.0	0.0	0.0	0.0	0.0
	Annual mean >16µg.m^{-3}	2.2	0.8	0.0	0.0	0.0
	Annual mean >12µg.m^{-3}	44.1	37.8	24.5	9.7	2.1
Benzene	Annual mean >5µg.m-3	0.0	0.0	N/A	N/A	N/A
CO	8 hour mean > 10mg.m^{-3}	0.0	N/A	N/A	N/A	N/A
1,3-butadiene	Annual mean > 2.25µg.m^{-3}	0.0	N/A	N/A	N/A	N/A
B[a]P	Annual mean > 0.5ng.m^{-3}	0.003	N/A	0.002	N/A	N/A

Table 2.3: Summary of modelled total percentage exceedences using a 2003 base year *(continued)*

Percentage of total population in the area exceeding (%) (total UK population assessed 58,160,071)						
Pollutant	**Threshold**	**2003**	**2005**	**2010**	**2015**	**2020**
SO^2	15 minute mean limit value	0.66	1.17	0.01	0.01	0.01
	1 hour and 24 hour limit value	0.01	0.01	0.01	0.01	0.01
NO_2	Annual mean >40μg.m^{-3}	4.0	2.3	0.6	0.3	0.3
PM_{10}	Annual mean >31.5μg.m^{-3}	0.1	0.1	0	0	0
	Annual mean >20μg.m^{-3} (rest of England 2010 objective)	88	81	51	32	20
	Annual mean >20μg.m^{-3} (Wales 2010 objective)	55	37	12	6	5
	Annual mean >20μg.m^{-3} (Northern Ireland 2010 objective)	40	2	4	2	7
	Annual mean >18μg.m^{-3} (Scotland 2010 objective)	19	19	4	2	2
	Annual mean >23μg.m^{-3} (London 2010 objective)	99	97	46	13	4
$PM_{2.5}$	Annual mean >20μg.m^{-3}	0.0	0.0	0.0	0.0	0.0
	Annual mean >16μg.m^{-3}	23.4	12.1	0.1	0.0	0.0
	Annual mean >12μg.m^{-3}	81.9	77.5	56.6	43.0	23.3
Benzene	Annual mean >5μg.m^{-3}	0.0	0.0	N/A	N/A	N/A
CO	8 hour mean >10mg.m^{-3}	0.0	N/A	N/A	N/A	N/A
1,3-butadiene	Annual mean >2.25μg.m^{-3}	0.0	N/A	N/A	N/A	N/A
B[a]P	Annual mean >0.5ng.m^{-3}	0.4	N/A	0.03	N/A	N/A

Sulphur dioxide

61. There are three objectives for SO_2:

- 15 minute mean concentration of 266μg.m^{-3} not to be exceeded more than 35 times a year from 31 December 2004;
- one hour mean concentration of 359μg.m^{-3} not to be exceeded more than 24 times a year from 31 December 2004; and
- 24 hour mean concentration of 125μg.m^{-3} not to be exceeded more than 3 times a year from 31 December 2004.

62. No exceedences of these objectives were measured in the national monitoring network (Automatic Urban and Rural network, AURN)[25] in 2004. Exceedences of the 15-minute mean objective were, however, modelled in 2003. Exceedences were also measured at monitoring sites not run by Defra and the devolved administrations. Exceedences are predicted to remain in 2005 but be almost eliminated by 2010.

63. Modelled exceedences of the 1-hour and 24-hour objectives are limited to the vicinity of one industrial plant. Further work will be undertaken to assess the likelihood of the objectives being met at this location.

Nitrogen dioxide

64. There are two objectives for NO_2:

- 1 hour mean concentration of 200µg.m^{-3} not to be exceeded more than 18 times a year from 31 December 2005; and
- annual mean concentration of 40µg.m^{-3}.

65. Both these objectives were met as an average for all AURN monitoring sites in 2004. The highest recorded measurements, however, did not meet the objectives.

66. The annual mean objective is expected to be met at all background locations across the UK by 2010 with only a small percentage (<1%) of total area assessed exceeding this value in 2003 and 2005. The objective is not expected to be met at all roadside locations under baseline conditions by 2020. However, the percentage of total major road length exceeding is expected to decline from around 53% in 2003 to around 9% in 2020.

PM_{10}

67. There are seven PM_{10} objectives to consider:

For the UK, an annual mean concentration of 40µg.m^{-3} by 31 December 2004;

68. The annual mean 2004 objective was met as an average of all AURN sites in 2004. The highest recorded measurements however did not meet the objectives. We expect exceedences at both background and roadside locations to be almost completely eliminated by 2010.

For the UK, a 24-hour mean concentration of 50µg.m^{-3} not to be exceeded more than 35 times a year by 31 December 2004

69. The 24-hour mean 2004 objective was met as an average of all AURN sites in 2004. The highest recorded measurements, however, did not meet the objectives.

70. An annual mean concentration of 31.5µg.m^{-3} (roughly equivalent to the 24-hour objective) is predicted to be met at background locations. We expect this concentration to be exceeded at some roadside locations for all years, with the percentage of total road length exceeding decreasing from around 16% in 2003 to less than 1% in 2020.

[25] See website www.airquality.co.uk

For the UK (apart from London), a 24-hour mean concentration of 50µg.m^{-3} not to be exceeded more than 7 times a year by 31 December 2010

71. This objective has not been modelled. It is too uncertain to predict 7 exceedences of a 24-hour mean concentration in any year. Exceedence is highly dependent on the weather.

For the UK (apart from Scotland and London), an annual mean concentration of 20µg.m^{-3} by 31 December 2010

72. Widespread exceedences of this objective were measured in 2004.

73. Despite improvements between now and 2010, we predict the objective to be exceeded at both background and roadside locations for all years.

For London, a 24-hour mean concentration of 50µg.m^{-3} not to be exceeded more than 10 times a year by 31 December 2010;

74. This objective has not been modelled. It is too uncertain to predict 10 exceedences of a 24-hour mean concentration in any year. Exceedence is highly dependent on the weather.

For London, an annual mean concentration of 23µg.m^{-3} by 31 December 2010

75. Widespread exceedences of this objective were measured in 2004.

76. Despite large improvements between now and 2010, we expect the objective to be exceeded at both background and roadside locations for all years.

For Scotland, an annual mean concentration of 18µg.m^{-3} by 31 December 2010

77. Widespread exceedences of this objective were measured in 2004.

78. The objective will be met nearly everywhere by 2010 at background locations but there may still be some exceedences close to urban roads.

$PM_{2.5}$

79. There are no current objectives for $PM_{2.5}$. We have considered performance against four illustrative $PM_{2.5}$ thresholds to illustrate changes in predicted concentrations in different years.

80. Allowing for uncertainty, we are fairly confident that an annual mean of 25µg.m^{-3} can be met nearly everywhere by 2010 under the baseline. An annual mean of 20µg.m^{-3} is predicted to be met everywhere at background locations and roadside exceedences of this concentration are expected to have been eliminated by 2015. We expect no background exceedences of an annual mean of 16µg.m^{-3} by 2010. Roadside exceedences are expected for all years. Background and roadside exceedences of an annual mean concentration of 12µg.m^{-3} are predicted for all years.

Benzene

81. There are three objectives for benzene:

For the UK, a running annual mean concentration of 16.25µg.m^{-3} to be met by 31 December 2003

82. Measurements show that this is being met by a wide margin.

For England and Wales, an annual mean concentration of 5µg.m^{-3} by 31 December 2010

For Scotland and Northern Ireland, a running annual mean concentration of 3.25µg.m^{-3} to be met by 31 December 2010

83. The objectives were achieved at all AURN monitoring sites in 2004. Modelled projections show that the objective is expected to be met at all background and roadside locations in 2010. The 2010 objective in Scotland and Northern Ireland is also expected to be met.

1,3-butadiene

A running annual mean concentration of 2.25µg.m^{-3} to be met by 31 December 2003

84. No AURN monitoring sites recorded exceedences in 2004. Moreover modelling of 1,3-butadiene for 2003 showed no predicted exceedences of the objective. Therefore projections have not been produced because emissions are expected to decline in the future. The objective is expected to continue to be met.

Ozone

8 hour mean concentration of 100µg.m^{-3} not to be exceeded more than 10 times a year by 31 December 2005

85. Measurements from the AURN network indicate that this objective was just met on average in 2004. The highest recorded measurements, however, did not meet the objectives.

86. Modelling of future ozone concentrations (see consultation document) suggests that, without additional measures, there is likely to be a gradual deterioration in ozone air quality. This is both for average levels and exceedences of the objective (episodes). Concentrations will still exceed the AQS objective in 2020. Average levels are likely to rise in urban and rural areas.

87. There are two main reasons for the projected increase:

- In addition to the role of NO_X emissions in regional photochemical ozone production, lower NO_X emissions reduce the local destruction of ozone, most notably in urban areas. This causes ozone concentrations in urban areas to increase towards the higher concentrations in surrounding rural areas.
- A second major factor leading to higher ozone concentrations is the long term increase in hemispheric background concentration.

Carbon monoxide (CO)

Maximum daily running 8 hour mean[26] concentration of 10µg.m^{-3} by 31 December 2003

88. No measurements in the AURN exceeded this objective in 2004. No CO projections have been produced for comparison with the objective. This is because there were no modelled or measured exceedences in 2003 and emissions from the main sources of CO are expected to decrease. Therefore no exceedences of CO are expected in future years and the objective is expected to continue to be met.

Lead

Annual mean concentration of 0.50µg.m^{-3} to be met by 31 December 2004

Annual mean concentration of 0.25µg.m^{-3} to be met by 31 December 2008

89. The 2008 lead objective is predicted to be met everywhere based on current concentrations in the monitoring network and hence no projections have been carried out.

Polycyclic aromatic hydrocarbons (PAHs)

Annual mean concentration of 0.25µg.m^{-3} to be met by 31 December 2010

90. The objective was exceeded at four urban background or industrial sites in the AURN in 2004. Modelling of PAHs is highly uncertain because of a highly uncertain emissions inventory. Indications are that the objective will be difficult to achieve in some areas due to domestic space heating and increased activity projected in the use of coal, anthracite and solid smokeless fuels.

Summary of air quality assessment

91. Overall, some AQS objectives are, and will remain, very challenging without further measures. These include 2010 annual mean PM_{10}, 2010 PM_{10} 24-hour mean, 2005 NO_2 annual mean and 2005 ozone daily maximum 8-hour mean. It is possible that there will be exceedences of the 2010 PAH annual mean objective in some locations, although this is more uncertain. Other objectives, including the SO_2, benzene, 1,3-butadiene, CO and lead objectives, are being met now or are likely to be met by their objectives years.

2.4.3.3 Results for ecosystems and vegetation objectives

92. Two types of baseline assessment were carried out in order to establish baseline data in relation to vegetation and ecosystems. The first focused on the air quality objectives for the protection of ecosystems contained in the 2000 Strategy and transposed from the First Air Quality Daughter Directive. These are based on *critical levels*, i.e. concentrations of pollutants in air above which damage to sensitive plants may occur.

93. The second baseline assessment focused on critical loads exceedences, brought about through deposition of pollutants. The process of depositing pollutants onto ecosystems can be split into three pathways. Dry deposition is the direct removal of the pollutant gas to vegetation, soils or other surfaces. Wet deposition is the incorporation of the

[26] Running 8 hour mean in Scotland.

pollutant into water droplets and then the removal from the atmosphere in rain or snow. Cloud droplet or particulate aerosol deposition occurs when either small water droplets or particles are removed by landing directly on surfaces. The combination of these processes provides the total deposition of the pollutant to the ecosystem.

94. While the UK Government and devolved administrations do not currently have a target for critical loads exceedences, the baseline assessment was necessary to calculate the impact on ecosystems of the additional measures discussed in Chapter 4. Further details of this assessment are given in section 4.3 of Chapter 4.

95. In summary, the baseline assessments showed that:

- The UK is currently in compliance with the air quality objectives for oxides of nitrogen and sulphur dioxide, and the baseline assessment shows that this will remain unchanged;
- Furthermore, there is the opportunity to extend the protection offered by the objectives to the great majority of areas important for nature conservation (SSSIs and Natura 2000 sites), without additional measures; and
- Currently in the UK, 55% of natural and semi-natural terrestrial habitats exceed their critical loads for acidity, and 60% for nitrogen deposition. The baseline assessment estimates that these figures will have fallen to 34% and 39% respectively, by 2020.

Air quality objectives baseline

96. The first Air Quality Daughter Directive set European limit values for oxides of nitrogen and sulphur dioxide to protect vegetation and ecosystems. The 2000 Strategy adopted these as UK air quality objectives, to be achieved by the end of 2000. It is important to define the areas in which the limit values are to be achieved. The Directive states that sampling points should be:

- at least 5 km from major emission sources; or
- 20 km from an agglomeration, which is defined as an area with a population of more than 250,000; and
- representative of areas of at least 1,000 km^2

97. The Directive allows for compliance to be demonstrated through a modelling approach which effectively simulates results from static continuous monitoring equipment. This is the approach which the UK has adopted. The base data used are the same as that used for the baseline assessments for nitrogen dioxide and sulphur dioxide, discussed earlier in this chapter. However, these data need to be modified in order to replicate the Directive requirements.

98. The first step is to define the areas in which the objectives apply and overlay these on maps showing 1 x 1 km grid square annual or winter average concentrations for nitrogen dioxide and sulphur dioxide. The concentration data is then aggregated to form 30 x3 0 km grid squares, excluding concentrations from within the ‘exclusion’

areas. This latter step is necessary in order to avoid averages from the 1 x 1 km squares within the exclusion areas falsely skewing the results for those areas where the objectives apply. The results for this assessment are shown in Table 2.4 below, and indicate that the objectives are currently being complied with.

Table 2.4: Compliance modelling results for vegetation and ecosystems objectives

Objective	Model outcomes for 2004, $\mu g.m^{-3}$			Result
	minimum value	maximum value	mean value	
SO_2 annual mean	0.6	7.0	1.4	No exceedences
SO_2 winter mean	0.7	9.2	1.8	No exceedences
NO_X annual mean	0.7	26.9	5.6	No exceedences

99. A further assessment was undertaken to assess air quality at Sites of Special Scientific Interest (SSSI) and Natura 2000 sites, both areas designated for their importance in nature conservation.[27] The assessment was applied to all designated sites, regardless of whether they were inside or outside the exclusions areas (around 37% of SSSIs and 53% of Natura 2000 sites lie within the exclusion areas). For this assessment, 30 x 30 km grid squares were used, and concentrations with the exclusion areas were included. Projections for the years 2010 and 2020 were undertaken using the FRAME model[28] and assuming baseline conditions.

2.5 Health benefits

100. Air pollution damages health and one of the major purposes of the AQS is to ensure a high degree of protection against risks to public health from air pollution. Healthy individuals are not thought to be at significant risk of short term effects from current levels of air pollution in the UK, but studies have indicated associations which persist at relatively low levels, between daily variations in levels of some pollutants and daily variations in mortality and hospital admissions for respiratory or cardiovascular conditions. The exact mechanisms are not yet known, but the advice of the Government's medical advisers is that it would be imprudent not to regard the associations as causal. Less is known about the effects of long term exposure to air pollutants but these are probably more important than the effects of short term exposure.

2.5.1 Overview of health effects of differing pollutants

101. Air pollutants have a range of effects on health: these have been considered in detail in Department of Health publications from both the Advisory Group on the Medical Aspects of Air Pollution Episodes (MAAPE)[29] and the Committee on the Medical Effects of Air Pollutants (COMEAP).[30] The health effects are also considered, in the context

[27] See section 4.2.7 of the consultation document for a further description of Natura 2000 sites.

[28] See http://www.frame.ceh.ac.uk for details of the FRAME model.

[29] Department of Health (1991; 1992; 1993; 1995a)

[30] Department of Health (1995b; 1995c; 2006a)

of economic analysis, in Chapter 2 of the 1999 report of the Ad-Hoc Group on the Economic Appraisal of the Health Effects of Air Pollution (EAHEAP).[31] A brief review, arranged by pollutant, is given below.

2.5.1.1 Particles

102. Evidence has accumulated in recent years to show that day to day variations in concentrations of airborne particles, measured as PM_{10}, $PM_{2.5}$, Black Smoke or other measures, are associated with day to day variations in a range of health end-points. These include daily deaths, admissions to hospital for the treatment of both respiratory and cardiovascular diseases and symptoms amongst patients suffering from asthma. These effects were reviewed in detail in the COMEAP report: Non- Biological Particles and Health, published in 1995.[32] When COMEAP reviewed the effects of air pollutants on health in their report: Quantification of the Effects of Air Pollution on Health in the UK (QUARK),[33] close attention was paid to identifying effects for which the evidence was sufficiently robust to allow quantification of effects in the UK. It was concluded that daily deaths and hospital admissions for the treatment of respiratory diseases met a series of criteria specified by COMEAP and could therefore be quantified. COMEAP subsequently published a statement confirming that the effect of particles on cardiovascular hospital admissions could also be quantified.[34] In addition to these effects there is evidence from the United States that long term exposure to particulate air pollution is associated with a decrease in life expectancy.[35] This has been discussed in a 2001 COMEAP report and a 2006 COMEAP statement.[36] This is considered the most important of the effects of particulate air pollution on health.

2.5.1.2 Health effects of PM_{10} and $PM_{2.5}$

103. There is much current debate about whether the effects of PM_{10} are in fact due to fine particles, $PM_{2.5}$. The Expert Panel on Air Quality Standards (EPAQS) considered this issue in its report on the most appropriate metric on which to base a particle standard.[37] It noted that some epidemiological studies have suggested that the main toxic component is likely to be in the finer fraction but several have indicated that the toxic effects may not be confined to this fraction. The report concludes that PM_{10} continues to provide the most appropriate basis for a standard although it recommends that the issue should remain under active review.

104. The crucial point for cost-benefit analysis is to ensure that the benefits correctly match the type of particles being reduced by the proposed policies. In fact, the vast majority of policies covered in this report reduce $PM_{2.5}$. The Health Effects Institute reanalysis

31 'Economic Appraisal of the Health Effects of Air Pollution', Ad-Hoc Group on the Economic Appraisal of the Health Effects of Air Pollution, Department of Health (1999).

32 'Non-Biological Particles and Health', Committee on the Medical Effects of Air Pollutants, Department of Health, (1995b). Available at http://www.advisorybodies.doh.gov.uk/comeap/state.htm.

33 'Quantification of the Effects of Air Pollution on Health in the UK', Committee on the Medical Effects of Air Pollutants, Department of Health (1998). Available at http://www.advisorybodies.doh.gov.uk/comeap/state.htm.

34 'Statement on Short Term Associations between Ambient Particles and Admissions to Hospital for Cardiovascular Disorders', Committee on the Medical Effects of Air Pollutants, Department of Health (2001b). Available at http://www.advisorybodies.doh.gov.uk/comeap/state.htm

35 Pope et al (1995); Health Effects Institute (2000); Pope et al (2002).

36 Department of Health (2001a; 2006b). Available at http://www.advisorybodies.doh.gov.uk/comeap/state.htm

37 'Airborne Particles: What is the appropriate measurement on which to base a standard? A Discussion Document', Expert Panel on Air Quality Standards, DETR (2001). Available at http://www.defra.gov.uk/environment/airquality/aqs/air_measure/index.htm

(Health Effects Institute, 2000) of the studies of long term exposure to particles found that the effect was more strongly linked to Gravimetric $PM_{2.5}$ than to PM_{10} or $PM_{10\text{-}2.5}$ (coarse particles). So applying these results to the policies discussed here is appropriate. For the short term effects, the concentration- response functions are based on PM_{10} (measured by TEOM). However, since $PM_{2.5}$ is included within PM_{10} and studies (Anderson et al, 2001) in the UK found it was difficult to distinguish the effect of $PM_{2.5}$ and PM_{10} due to their close correlation with each other, it is unlikely that the benefits are misrepresented. The only situation in which this would be the case would be if all the effects of PM_{10} were due to the coarse fraction alone. Although the EPAQS report noted some evidence for an effect of the coarse fraction and could not rule out a contribution from the coarse fraction, there was no suggestion that all or even the majority of the effect of PM_{10} resided in the coarse fraction.

2.5.1.3 Sulphur dioxide

105. Sulphur dioxide is an irritant gas that, in high concentrations, provokes bronchoconstriction: i.e. narrowing of the airways. Epidemiological studies, including some from the UK, have shown, as in the case of particles, that day to day variations in concentrations of sulphur dioxide are associated with the number of deaths occurring each day and also with admissions to hospital for the treatment of respiratory diseases. There is also evidence linking concentrations of sulphur dioxide with chest symptoms and with the use of bronchodilator therapies. There is evidence from the United States[38] that long term exposure to sulphur dioxide itself may be linked to losses in life expectancy. The same studies also indicated that sulphate particles may increase the risk of death. Sulphates are produced by oxidation of sulphur dioxide.

2.5.1.4 Nitrogen dioxide

106. The QUARK report (Department of Health, 1998) recorded inconsistencies in the evidence relating to the effects of nitrogen dioxide on health. Increases in daily deaths were found to be associated with increases in daily mean concentrations of nitrogen dioxide but this finding was not supported by evidence of effects on either respiratory or cardiovascular deaths. There is some evidence that hospital admissions for respiratory diseases are related to concentrations of nitrogen dioxide although COMEAP did not consider the evidence robust enough for quantification. UK work has shown that exposure to nitrogen dioxide enhances response to allergens and may increase the prevalence of respiratory infections in children. Volunteer studies have shown effects on lung function in asthmatics. There is some evidence for long term effects of nitrogen dioxide although the evidence is weak. It should be noted that nitrogen dioxide can be converted to nitrate which is a component of the particle aerosol. Nitrogen dioxide can also contribute to ground level ozone via a complex series of photochemical reactions which also involve volatile organic compounds.

[38] Health Effects Institute (2000); Pope et al (2002).

2.5.1.5 Ozone

107. Evidence for associations between daily deaths and admissions to hospital with daily mean concentrations of ozone is strong. It is not currently known whether there is a threshold of effect for the effects of ozone on health: evidence can be marshalled for and against such an assumption. COMEAP is currently working on a report on this issue. The QUARK report (Department of Health, 1998) concluded that only the data relating to daily deaths and respiratory admissions was sufficiently well founded to be used for quantification of effects on health in the UK. Volunteer studies have shown irritant effects on the airways. There is evidence from US studies that long term exposure to raised ozone concentrations leads to lower levels of lung function and may impair development of lung function. Whether this occurs in the UK is unknown. The evidence regarding whether long term exposure to ozone increases mortality is not clear cut.

2.5.1.6 Other pollutants

108. Other pollutants such as lead, carbon monoxide, benzene, butadiene and PAHs are considered in Chapter 4 (section 4.4) and Chapter 5.

2.5.2 Quantification methodology: short term exposure

2.5.2.1 Concentration-response coefficients – effects of short term exposure

109. Because both the concentration of air pollutants and the density of population vary across the UK, modelling of exposure to pollutants is needed in calculating their effects on health. This was the approach adopted in the report published by COMEAP early in 1998 on the Quantification of the Effects of Air Pollution on Health in the United Kingdom (Department of Health, 1998).

110. The literature on the effects of air pollutants on health is extensive and has not been reviewed for this report. This was felt to be unnecessary as the COMEAP report had examined the relevant evidence and had produced a series of coefficients linking concentrations of the major pollutants with effects on health. The coefficients used in this analysis are presented in Table 2.5.

Table 2.5: Concentration response coefficients

Pollutant	Health outcome	Concentration-response coefficient[a]
PM_{10}	Loss of life expectancy (long term exposure)	See later section 2.5.3
	Deaths brought forward (all causes) (short term exposure)[b]	+ 0.75% per 10μg.m^{-3} (24 hour mean)
	Respiratory hospital admissions	+ 0.80% per 10μg.m^{-3} (24 hour mean)
	Cardiovascular hospital admissions	+ 0.80% per 10μg.m^{-3} (24 hour mean)
Sulphur dioxide	Deaths brought forward (all causes)	+ 0.6% per 10μg.m^{-3} (24 hour mean)
	Respiratory hospital admissions	+ 0.5% per 10μg.m^{-3} (24 hour mean)
Ozone	Deaths brought forward (all causes)[c]	+ 0.6% per 10μg.m^{-3} (8 hour mean)
	Respiratory hospital admissions[c]	+ 0.7% per 10μg.m^{-3} (8 hour mean)
NO_2	See note[d] below	See note[d] below

Notes:

[a] Note to compare the "relative potency" of the pollutants, the coefficients should be compared on a molar or volume basis.

[b] The effects of short term exposure to particles have been considered as a sensitivity analysis in this report, not because the results are more uncertain than for other pollutants (they are well established), but because the results of the studies on long term exposure to particles probably include the short term effects (see Annex 2, section A2.6.1). Particles concentrations measured by TEOM[39] were used for short term effects and gravimetric particles concentrations were used for long term effects (to match the studies from which the exposure response functions were derived).

[c] Coefficients of 0.3% per 10μg.m^{-3} ozone for deaths brought forward were used in a sensitivity analysis. These are from a more recent WHO meta-analysis that has not yet been discussed by COMEAP.

[d] COMEAP did not consider that the evidence on NO_2 was sufficiently robust for quantification but did give a coefficient of 0.5% per 10μg.m^{-3} for an effect on respiratory hospital admissions. This coefficient has been used in this report but for sensitivity analysis only.

Source: Department of Health (1998; 2001a; 2001b)

111. Table 2.5 shows that concentration response coefficients were specified for particulate matter, ozone and sulphur dioxide. The Committee also examined nitrogen dioxide and carbon monoxide but felt that the evidence was not sufficiently strong to allow firm estimates of total effects on health to be made. In the case of nitrogen dioxide, a concentration response coefficient was defined for respiratory hospital admissions. Nitrogen dioxide was also discussed in the EAHEAP report (Department of Health, 1999) which suggested that this coefficient could be used for a sensitivity analysis.

[39] See Box 2.1 for a further description of the differences between TEOM and gravimetric measurements.

112. COMEAP (Department of Health, 1998) calculated the ozone impacts using two different assumptions: no threshold or a threshold at 50 ppb. We have followed this here. COMEAP are reviewing the evidence on whether or not there is a threshold for ozone but this is not yet published. WHO concluded that there was evidence that associations existed below the current guideline value (60 ppb), but their confidence in the existence of associations with health outcomes decreased as the concentrations decreased (WHO, 2004a).

113. In addition to these two assumptions, we have also included an assumption of a threshold at 35ppb as a sensitivity analysis for comparison with calculations done at a European level. This was not based on direct evidence of a threshold for health effects at 35 ppb. It was recommended on the basis of a combination of the uncertainty in the shape of the concentration response function at low ozone concentrations, the seasonal cycle and geographical distribution of background ozone concentrations and the range of concentrations for which European ozone modelling provided reliable estimates (UNECE/WHO, 2004).

114. The ozone modelling undertaken for this analysis[40] takes more account of local titration of ozone with nitric oxide and ozone deposition and is at a finer spatial resolution than the European RAINS modelling. Thus, there is less reason to use a cut-off at 35 ppb. However, the cut-off was included to allow comparison with European calculations. Use of the 35 ppb cut-off omits a lot of the increases in ozone concentrations seen as a result of reducing NO_X but it can be useful to distinguish this effect from effects on decreasing photochemical production of ozone.

115. For the 50 ppb threshold calculation, days under 50 ppb were set to zero. For other days, 50 ppb was subtracted from the relevant concentration. The concentrations were then averaged over the year giving the annual mean of concentrations in excess of 50 ppb. The equivalent calculation was also done for concentrations over 35 ppb.

116. A concentration response function of 0.3% per 10μg.m^{-3} for mortality was used as a sensitivity analysis. This was based on a more up to date WHO meta-analysis (WHO, 2004b) that has not been considered by COMEAP.

117. The health effects that were considered to be a result of short term exposure were daily deaths and admissions to hospital for the treatment of respiratory or cardiovascular diseases. In both cases the COMEAP report made clear that the numbers of events calculated as related to exposure to air pollution could not be simply interpreted as extra events. Deaths are brought forward and hospital admissions may be either brought forward or caused de novo. The extent of advancement of deaths and hospital admissions cannot yet be calculated and estimates of from a few days or weeks to a year have been produced. This inability to calculate the extent of advancement of these events is due to the nature of the epidemiological studies upon which the estimates are based: i.e. time-series studies. Some recent studies have used new statistical techniques to address this in the case of particles and all cause mortality. It was clear that the effect was not solely due to deaths occurring just a few days early but at least some of the deaths could be occurring at least 2 months early and probably more (see Annex 2).

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[40] Hayman et al (2005) 'Modelling of Tropospheric Ozone', AEA Technology, National Environmental Technology Centre. Report AEAT/ENV/R/1858

118. The 1998 report prepared by COMEAP stressed that other effects on health including effects on respiratory symptoms and the use of therapeutic drugs might also be increased by exposure to air pollution. The 1999 EAHEAP report also noted that there is data on associations between GP consultations and air pollution. The available data did not allow firm estimates of the size of these effects to be made. The uncertainties and possible omissions of types of effects which may be increased by air pollution are discussed further in Chapter 5.

119. Ideally, for a cost-benefit analysis, some indication of the relative significance of the non-quantifiable health effects should be given. This depends on a wide variety of different factors including strength of evidence, size of concentration-response function, ambient concentrations/extent of exceedences, presence or absence of a threshold, numbers of susceptible people and monetary values. For example, minor effects at an individual level may become important in public health terms if large numbers of people are affected and a pollutant with weak effects may be more important if present at higher concentrations.

120. The strength of evidence and possible size of the concentration response functions is discussed in the EAHEAP report when suggesting which of the non-quantifiable effects might be examined in a sensitivity analysis.

2.5.2.2 Method of calculation – effects of short term exposure

121. In calculating the effects of pollutants on health the following sequence of steps has been adopted. These steps are described in more detail in the COMEAP Quantification Report (Department of Health, 1998); the EAHEAP report (Department of Health, 1999) and a report from Netcen.[41]

a) The country has been divided into 1km grid squares and the annual average concentration of pollutants and resident population has been estimated for each. The former has been derived from the national mapping of the UK pollution climate[42] and the latter from census data.[43] Population-weighted mean concentrations are then calculated by region or for the whole of the UK.

b) A baseline level of the given health-related and pollution affected events e.g., daily deaths, hospital admissions for the treatment of respiratory diseases has been obtained from national statistics.[44]

c) By combining the data from (a) and (b) and applying a coefficient linking the pollutant concentration with the relevant effects, the magnitude of the expected health effects can be derived. For this report, the coefficient is applied to the

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[41] Stedman et al (2002) 'Quantification of the Health Effects of Air Pollution in the UK for Revised PM10 Objective Analysis', a report produced for the Department for Environment, Food and Rural Affairs, Welsh Assembly Government, The Scottish Executive and the Department of the Environment in Northern Ireland. Contract Number EPG 1/3/146

[42] Grice et al (2006); Stedman et al (2006)

[43] The calculations performed at Netcen used population data based on the 2001 census giving a total UK population of 58,279,138.

[44] Baseline rates were obtained from ONS for mortality (www.statistics.gov.uk) and from the Department of Health (www.hesonline.nhs.uk) for hospital admissions. The baseline rates used for this report were as follows: all cause deaths excluding external causes 989.7 per 100,000 for 2001; emergency respiratory hospital admissions (ICD10 J00 to J99) 979.7 per 100,000 for 2003/4; emergency cardiovascular admissions (ICD10 I20 to I52) 981.4 per 100,000 for 2003/4. Rates for England and Wales (deaths) or England (hospital admissions) were assumed to apply to the whole of the UK.

expected fall in concentration from the additional policies being assessed. This will give the benefit to health produced by the fall in concentrations of air pollutants expected to occur under the additional policies.

122. Acute effects calculations are carried out using raw TEOM data for the change in PM_{10} concentration as recommended by COMEAP (Department of Health, 1998). In terms of quantifying the impacts of the different measures, the calculations were done on an annual basis using the 2010 concentration reduction for 5 years, the 2015 concentration results for 5 years and the 2020 concentration results for the remaining 90 years. In terms of presentation of results in both the consultation document and Chapter 3 of this report, the acute effects assessed as part of the central analysis are presented as annual physical impacts: the 2020 estimates are presented for those measures considered to have a sustained effect on pollution and the 2010 estimates are presented for shorter term measures. The way in which the estimates have been used in terms of valuing the impacts is described in section 2.5.5 below.

123. The COMEAP report in 1998 was based on urban areas only (most studies of health effects were done in cities). The calculations are based on all areas here but urban areas do in fact dominate the population weighted mean as both population and pollution are higher in urban areas.

2.5.3 Quantification methodology: long term exposure to particles and mortality

124. Studies in the United States (Dockery et al 1993; Pope et al 1995) have shown that those living in less polluted cities live longer than those living in more polluted cities. After adjustment for other factors, an association remained between ambient concentrations of fine particles ($PM_{2.5}$) and shorter life expectancy. In its 1998 report, COMEAP did not recommend that these studies should be used as a basis for quantifying the effects on health of long term exposure to particulate air pollution in the UK. However, it was noted that, had these studies been used, the assessment of the overall impacts of particulate air pollution would have been considerably increased.

2.5.3.1 COMEAP report 2001

125. Subsequently, COMEAP published a further report on the long term effects of particles on mortality (Department of Health, 2001a). This considered two reports[45] which provided further analysis of the earlier results of the US studies. COMEAP concluded that it was more likely than not that a causal association existed between long term exposure to particles and mortality. This was considered transferable to the UK although it was noted that the quantitative impact might not be exactly the same. The Committee considered it was preferable to assess the size of the effect and comment on it rather than ignore it but emphasised that there were great uncertainties in the process which needed to be made clear.

126. The key uncertainties were whether the results could be explained by undetected confounding, whether high exposures in the past lead to an overestimation of the effect, what lag times and what duration of exposure are required for the effect and a lack of understanding of the underlying mechanism.

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[45] Health Effects Institute (2000); Institute of Occupational Medicine (2000)

2.5.3.2 Hazard rates

127. Bearing these uncertainties in mind, the Committee developed a series of estimates of the expected gains in life years for a sustained 1µg.m^{-3} drop in $PM_{2.5}$ with comments on its confidence in them. The calculations were based on an illustrative scenario of the population of England and Wales alive in 2000 followed for their lifetime until all would have died (105 years). The range of reductions in hazard rate were based on Pope et al (1995) and the HEI reanalysis (Health Effects Institute, 2000). The estimates are shown in the following table. (More details of the methodology for deriving these types of estimates are given later in the chapter, in the COMEAP (Department of Health, 2001a) report and in the Institute of Occupational Medicine (2000) report.)

Table 2.6: Reductions in hazard rate from a unit drop in fine particles

Reduction in hazard rate	Total life years gained (millions)	COMEAP comments
Rough comparison based on PM_{10} effect in time-series studies	0.007 – 0.02	Estimate considered highly likely to be at least this large. Time-series studies well replicated. Represents the possibility that the apparent long term effect of particles is actually explained by unknown confounders.
0.1% from lower adjusted relative risks in HEI report	0.2 – 0.5	Estimate considered most likely to be around this size. This takes account of the small number of confounding factors that substantially reduced the relative risks in the HEI reanalysis.
0.3% from lower CI 1.09 (ACS)	0.6 – 1.4	Estimate considered reasonably likely but higher than predicted by some of the adjusted relative risks in the HEI reanalysis.
0.6% from relative risk of 1.17 in ACS study	1.2 – 2.8	Estimate considered less likely. In most cases, factors examined in the HEI reanalysis did not markedly affect the relative risk but some did and there may also be unknown confounders. Higher exposures in the past may also lead to an overestimate of the risk at current levels.
0.9% from upper CI 1.26 (ACS)	1.8 – 4.1	Estimate considered implausibly large for the reasons given above and in comparison with other risks or total changes in life expectancy in recent years.

Estimated total gains in life years (millions) in population of England and Wales 2000, followed to extinction with a range of reductions in hazard rates in those aged 30 years and over. Total effects immediate, phasing in gradually or step function after up to 40 years based on a 1µg.m^{-3} drop in annual mean $PM_{2.5}$. (This is why the figures are given as a range in the second column of the table.) Estimate of effect in time-series studies based on a 1µg.m^{-3} drop in annual mean PM_{10} assuming a coefficient of 0.075%, a loss of life expectancy of 2 to 6 months per death brought forward and a similar effect on all ages. CI – confidence interval. ACS American Cancer Society study. Source: Department of Health (2001a)

128. The key points are the reductions in hazard rate and the comments on them. Some of these reductions in hazard rate are used[46] with a different population scenario in the benefit analyses later in the report. (COMEAP noted that different populations and follow-up periods than those used in their illustrative population scenario might be needed in cost-benefit work and that this was acceptable provided the same methodology was used.)

129. The Committee noted that the HEI reanalysis (Health Effects Institute, 2000) had examined an expanded range of potential confounders such as the level of income, income disparity, poverty and unemployment and had found no marked impact on the result. Level of education was found not to be a confounder, although it was an effect modifier (i.e. the effect of long term exposure to fine particles on mortality remained after adjustment for level of education but the effect was found to be greater in those with a low level of education). However, adjustment for a minor number of potential confounders such as population change and sulphur dioxide did reduce the relative risks substantially. The Committee noted that there could be other unknown confounders and it was possible that some of the apparent effect of current levels was, in fact, due to higher exposures in the past, leading to an overestimation of the coefficient.

130. For the above reasons, although opinions differed at that time,[47] the majority of the Committee preferred the estimate based on the 0.1% reduction in hazard rate per $\mu g.m^{-3}$ $PM_{2.5}$. However, the Committee also considered that, given the uncertainties, it was unwise to just give a single estimate and recommended use of the above range of estimates in sensitivity analyses.

131. It was also considered possible, although unlikely, that there were no long term effects, if the results were explained by unknown confounders, confounding by sulphur dioxide or lack of control for spatial variations in mortality. If so, the only effect on mortality would be that of the short term associations detected in the time-series studies.

132. For the purposes of comparison, a rough estimate of the gain in life expectancy expected from a reduction in the short term effects was included in the first row of the above table. This is based on PM_{10} not $PM_{2.5}$ and had to be calculated differently because based on a different type of study. A loss of life expectancy of 2-6 months was assumed per death brought forward. (As mentioned above, the loss of life expectancy per death brought forward cannot be estimated directly from the time-series studies but there are indications from other studies that it could be 2 months or more (see discussion in Department of Health, 2001a.)) This is not translated into a reduction in hazard rate (because calculated in a different way) but similar calculations will be discussed further later in the chapter. Although very approximate, it does indicate that the effects of long term exposure on life expectancy could be considerably greater than the effect of short term exposure on life expectancy. However, the effects would still be very much less than those, for example, of active tobacco smoking.

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[46] Updated to reflect recent COMEAP views (see section 2.5.3.6).

[47] See section 2.5.3.6 for updated view.

2.5.3.3 New studies published since 2001

133. COMEAP has not considered the effects of long term exposure to particles on mortality since 2001 but is doing so as part of an update of its 1998 Quantification Report (Department of Health, 1998). A new sub-group has been set up for this purpose and will report in 1 to 2 years time. An interim statement from this sub- group has been published – see section 2.5.3.6.

134. In the meantime, some comments on new developments[48] in this area are given below.

135. Pope et al (2002) has published a longer follow-up of the Pope et al (1995) study. This increases the statistical power of the study. This new paper also included further developments in analysis such as incorporating dietary variables (e.g. fat and vegetable consumption) and including various methods of control for spatial variation. The effect of particulate pollution at two different time periods was also examined.

136. The main analysis confirmed the previous findings for all cause mortality.[49] The relative risk for all cause mortality for a 10µg.m^{-3} change in $PM_{2.5}$ (averaged over the two time periods) was 1.06 (1.02 – 1.11).[50] The relative risk was slightly lower when using the more distant time period (1979-1983) to represent exposure than when using a more recent time period (1999-2000), suggesting more recent exposure might be important.

137. The paper did not report a relative risk for $PM_{2.5}$ adjusted for sulphur dioxide, although a clear positive association between long term exposure to sulphur dioxide and all cause mortality was again confirmed. The possible effect of adjustment for population change (which reduced the relative risk in the HEI reanalysis) was not reported.

138. Hoek et al (2002) published the results of a cohort study in Europe (the Netherlands). Although of a different design (exposure to black smoke and nitrogen dioxide was measured at a smaller spatial scale, taking account of the proximity of an individual's home address to a major road), this study provided broad confirmation that long term effects of particles can be found with the air pollution mixture found in Europe. The relative risk for all cause mortality was 1.32 (0.98 – 1.78) per 10µg.m^{-3} black smoke (this is not directly comparable with Pope et al (2002) as it refers to a different particle metric with a different spatial distribution). The possible long term effects of sulphur dioxide were not examined in this study.

139. Jerrett et al (2005) has reported a relative risk for all cause mortality of 1.17 (1.05-1.30)[51] per 10µg.m^{-3} $PM_{2.5}$ in a study in Los Angeles. A portion of the American Cancer Society cohort studied by Pope et al (2002) was used but exposure was assigned at a smaller spatial scale using interpolation of air pollution concentrations from local

[48] This section highlights a few interesting new developments. For a fuller discussion see the forthcoming COMEAP report on quantification.

[49] The relative risk for lung cancer mortality was increased and statistically significant in Pope et al (2002) but was only slightly increased and was not statistically significant in the previous study with shorter follow-up (Pope et al, 1995). The results for cardio-pulmonary mortality were confirmed as positive and statistically significant.

[50] In this section, relative risks are given followed by the 95% Confidence Intervals in brackets.

[51] A relative risk of 1.11 (0.99 – 1.25) was found after control for additional city level covariates such as income inequality.

monitors. The possible long term effects of sulphur dioxide were not examined but sulphur dioxide levels are low in California.

140. A key question is the interpretation of the findings regarding sulphur dioxide. If the associations seen are due, in part, to sulphur dioxide itself, then the size of the association with particles is probably smaller than that reported. Some researchers have suggested that it is more likely that sulphur dioxide is acting as a better marker for local sources of combustion particles than $PM_{2.5}$ (in which case the total pollution effect could still be allocated to particles). On the other hand, a clear association between a fall in sulphur dioxide and mortality was found in Hong Kong after a move to low sulphur fuel, in the absence of changes in overall PM_{10} levels[52] (Hedley et al 2002). Falls in mortality have also been seen after a ban on coal sales in Dublin which reduced both black smoke and sulphur dioxide levels (Clancy et al 2002) but a cohort study in Norway did not find an association between sulphur dioxide and mortality (Nafstad et al 2004).

2.5.3.4 World Health Organisation recommendations

141. The European Commission asked the World Health Organisation (WHO) for advice on the health effects of particles. The WHO's response (WHO, 2003)[53] included an overview of the studies of the effects of long term exposure to particles on mortality. WHO noted the extensive scrutiny that was applied in the HEI reanalysis (Health Effects Institute, 2000) and the fact that this largely corroborated the findings of the original two US cohort studies (Dockery et al 1993; Pope et al 1995).

142. The WHO report mentions the major concern that spatial clustering of air pollution and health data in the American Cancer Society (ACS) study made it difficult to disentangle air pollution effects from those due to the underlying spatial auto- correlation of the mortality data. The report goes on to note that the authors of the extension of the ACS study (Pope et al 2002) reported that the study did not reveal significant spatial auto-correlation.

143. Concern about the role of sulphur dioxide was also noted as inclusion of sulphur dioxide in multi-pollutant models decreased the PM effect estimates considerably in the reanalysis and this point was not further addressed in the extension of the ACS study. WHO quoted the HEI reanalysis view that the spatial adjustment may have over-adjusted (i.e. reduced) the estimated effects of regional pollutants such as $PM_{2.5}$ compared with more local pollutants such as sulphur dioxide (although this point only applies to the spatial adjustment models and not to the main analysis).

144. The WHO response described a small number of other studies on long term exposure of particles and mortality including the Dutch cohort study mentioned in paragraph 138 above. The paper by Jerrett et al (2005) was not available at the time of WHO's considerations.

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[52] Although it has been suggested that there could have been a change in concentrations of heavy metals (Hedley et al (2005), available at http://pbc.eastwestcenter.org/Abstract2005Hedley.htm). This may represent a change in composition of the particles since heavy metals are often carried on particles.

[53] WHO provided a further response to the European Commission in 2004 but this second response did not cover the effects of long term exposure to particles in any detail.

145. It is important to note that this was a brief overview intended to show that further data had become available since the WHO Air Quality Guidelines were last published in 1997. It was concluded that the WHO Air Quality Guidelines needed to be updated with regard to particles – this will involve a more detailed review of the evidence.[54] The overview was not intended to recommend a concentration-response function for health impact assessment.

146. WHO has recommended a concentration-response function for estimating the impact of long term exposure to $PM_{2.5}$ in a few paragraphs in a summary report prepared by the joint WHO/UNECE Task Force on the Health Aspects of Air Pollution (UNECE/WHO, 2003). It was proposed that the relative risk for all causes of mortality for the average exposure level from the extension of the ACS study (Pope et al 2002) should be used. (This is equivalent to a 0.6% change in hazard rate per $\mu g.m^{-3}$ $PM_{2.5}$). The use of the average exposure relative risk rather than the relative risk for the recent or earlier time period was discussed. There was also discussion of the fact that the ACS cohort had above average educational status but that the long term effects appeared to be greater in those with low educational status. However, there was no discussion of spatial auto-correlation or of adjustment (or not) for possible effects of sulphur dioxide.[55]

2.5.3.5 Summary – implications of recent studies and exposure response coefficients

147. There is a consensus that there is sufficient evidence for an effect of long term exposure to particles on mortality and that this effect should be quantified. However, there is considerable uncertainty over the size of the effect. COMEAP considered this issue in detail and recommended use of a range of estimates. These recommendations have been used in the analyses in this report. Further studies have been published since COMEAP's 2001 recommendations and this has led COMEAP to reconsider the issue (see next section). It is worth noting the following:

- there are now a larger number of cohort studies reporting an association between long term exposure to particles and mortality;
- the findings of the US cohort studies have now been broadly confirmed in Europe; and
- some studies found larger relative risks than in the ACS study although on a more local scale.

2.5.3.6 New COMEAP Interim Statement

148. COMEAP has recently issued an interim statement on mortality and long term exposure to air pollutants, particularly relating to ambient particles.[56] This is based on a detailed consideration of the more recent evidence and factors that can affect the best estimate of the size of the coefficient such as adjustment for sulphur dioxide, spatial

[54] A summary of the more detailed review is now available http://www.who.int/phe/air/aqg2006execsum.pdf This summary emphasises the importance of the long-term exposure evidence but does not comment further. There is more discussion in the full version now published (WHO, 2006a).

[55] A longer report has now been published (WHO, 2006b). This quotes the points made on spatial autocorrelation and sulphur dioxide in the WHO response to the European Commission (WHO, 2003), as described in paragraphs 142-143 above.

[56] 'Interim Statement on the Quantification of the Effects of Air Pollutants on Health in the UK', Committee on the Medical Effects of Air Pollutants, Department of Health (2006b).
Available at http://www.advisorybodies.doh.gov.uk/comeap/pdfs/interimlongtermeffects2006.pdf

autocorrelation and measurement error and the higher coefficients found in studies at smaller spatial scales.

149. On balance, the Committee recommended using a coefficient of 6% per 10µg.m^{-3} $PM_{2.5}$ from the largest most extensively analysed cohort study (Pope et al, 2002). The Committee quoted the 95% confidence intervals for this coefficient (2% to 11%) as an interim uncertainty range but noted that this only represented the statistical (sampling) uncertainty and not other factors contributing to uncertainty. On the other hand, in terms of the statistical (sampling) uncertainty it is more likely that the true coefficient lies close to the centre rather than close to the boundaries of the 95% interval. The Committee wished to consider these issues further before finalising their view on uncertainty. The Committee also commented on the lag time between exposure and effect. This is discussed further in section 2.5.3.10 below.

New COMEAP Report

150. COMEAP has now published a full report for comment on the effects of long-term exposure to air pollution on mortality (Department of Health, 2007). The main recommendation to use a coefficient of 6% per 10µg.m^{-3} $PM_{2.5}$ remains as in the interim statement. An uncertainty distribution has been derived, from the arithmetic mean of the individual probablilities, taking into account Members' views on the wider uncertainties. This distribution can be summarised in various ways including a 95% uncertainty interval of 0% to 15%. (The wider range compared with the 95% confidence interval quoted above reflects the fact that other aspects of uncertainty have been included in addition to the statistical (sampling) uncertainty). Summarising the distribution in this way does not include information on the relative likelihood of the possible values for the coefficient within the 0% to 15% interval. For this reason, it is recommended that the full distribution be used in Monte Carlo analysis for the best representation of uncertainty. If 'typical low' and 'typical high' values are required for sensitivity analysis, the report suggests use of the 12.5th and 87.5th percentiles (1% and 12%). These uncertainty issues are discussed in more detail in section 5.3 of Chapter 5 and further analysis of the probability distribution of hazard rates for chronic mortality effects has been included as part of the recent Monte Carlo analysis presented in section 5.6 of Chapter 5.

2.5.3.7 Method for calculating numbers of life years gained

151. The methodology is based on that in the IOM report, published in 2000, and a subsequent publication[57] although slightly different assumptions have been used (Department of Health, 2001a).[58] The basic strategy, for a given population, is to:

- obtain information on current mortality rates;
- predict future mortality using current rates and lifetables (see Box 2.2 below) and some assumptions about future demography, in the absence of changes in air pollution;

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[57] Institute of Occupational Medicine (2000); Miller, B.G. and Hurley, J.F. (2003).

[58] Department of Health (2007) Committee on the Medical Effects of Air Pollutants 'Long-term Exposure to Air Pollution: Effect on Mortality' Draft report for technical comment.
http://www.advisorybodies.doh.gov.uk/comeap/statementsreports/longtermeffectsmort2007.pdf

- create an alternative scenario by adjusting mortality rates according to evidence regarding the effect of pollution on mortality, but leaving other baseline assumptions unchanged;
- compare predicted life expectancy (or some other appropriate summary measure) between the scenario without pollution changes and the alternative scenario, to give estimates of the effect of the pollution change; and
- examine how sensitive these estimates are to changes in the underlying assumptions.

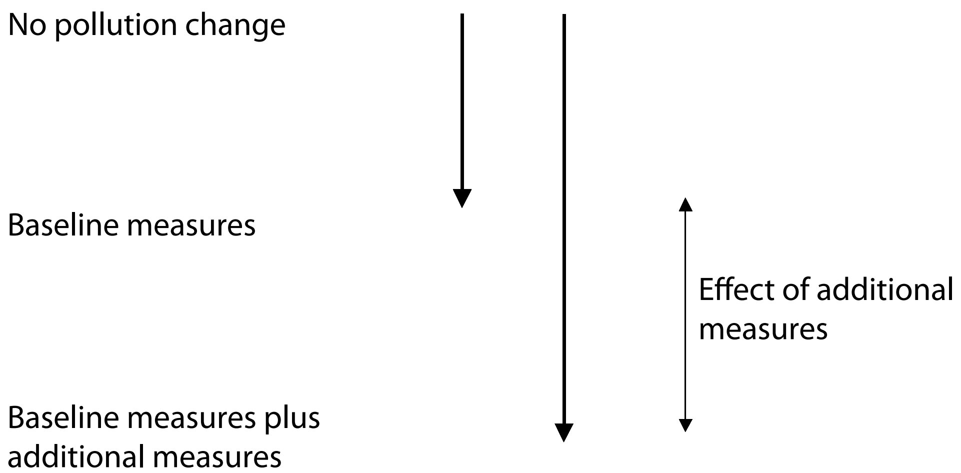
152. Two calculations were performed. The difference in life years between the baseline pollution changes (expected due to measures already planned) and the scenario without pollution changes was calculated. Then the life years saved for the additional measures scenario (the baseline pollution changes plus the pollution changes from any proposed additional measures) were calculated relative to the scenario without pollution changes. Finally, the difference between these two calculations was derived giving the life years saved for the proposed additional measures.

Box 2.2 What is a lifetable?

A lifetable is a technique used to summarise the patterns of survival in populations. It uses age-specific death rates, derived from numbers of deaths in each age group and mid-year population sizes for each age group. Standard lifetable calculations compute survival rates at different ages, either from birth or from a specific achieved age. From these, the total numbers of life years lived at each age can be derived, as can average life expectancy.

Figure 2.3

Impact of additional measures



153. The scenario with no pollution changes is based on the numbers of deaths in each sex and age group[59] found in England and Wales in 1999. This is used to predict future mortality. It is assumed that the mortality rates identified in 1999 will not change over time, that birth rates will remain constant and that the net effect of migration does not alter population sizes or mortality rates. (The IOM report found that changing these assumptions had only a small effect on the results.) The lifetable calculations were applied to give the total life years lived for the (predicted) population of England and Wales in 2010, including all new cohorts born right up to 2109, followed up to 2109[60] (see Figure 2.4).

2.5.3.8 Derivation of unit impact factor

154. The calculation of the long term effects was done in two stages. Firstly, the Institute of Occupational Medicine (IOM) was commissioned to calculate the gain in life years for an illustrative 1% drop in hazard rate. The 1% drop was chosen for arithmetic convenience to provide a unit impact factor. Secondly, this was scaled to the appropriate drop in hazard rate per $\mu g.m^{-3}$ $PM_{2.5}$ (e.g. 0.6%) and to the drop in pollutant concentration being examined (e.g. $0.5\mu g.m^{-3}$ $PM_{2.5}$). Previous work by IOM had shown that the results scale approximately linearly according to the change in mortality rate. This section describes the first stage.

2.5.3.9 Different durations of pollution reductions

155. The simplest interpretation of the cohort studies is that the long term averages used represented lifetime exposure, although the ACS study had no direct information on the duration of exposure required. We modelled a sustained reduction in pollution throughout a lifetime.[61] Most of the additional measures start around 2010, so the reduction in pollution was applied in 2010 and maintained for the remainder of the life time of those alive in 2010. This was assumed to be up to 100 years,[62] meaning follow up of the lifetables was stopped in 2109.

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[59] For single years up to age 89 and a total for 90+. Mortality rates for 90+ were applied to all ages 90-105 inclusive.

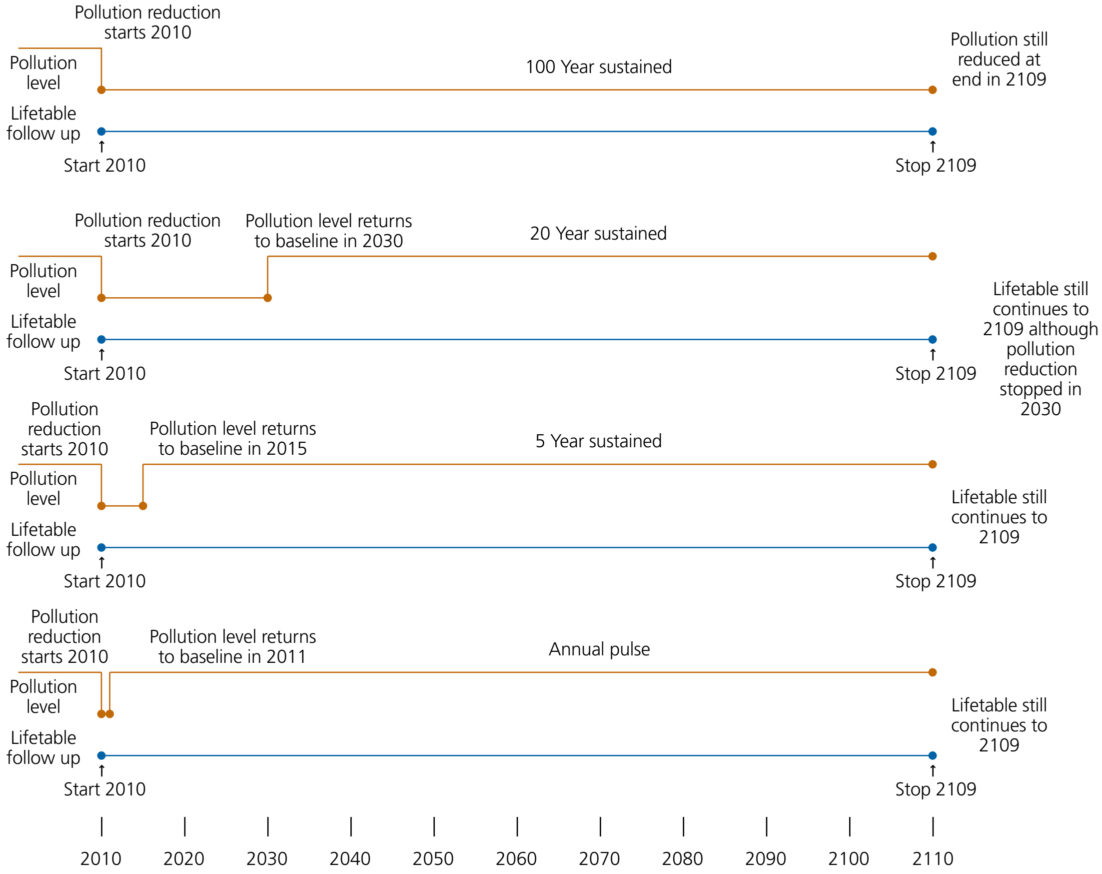
[60] Excluding new births would underestimate the benefits. The previous IGCB report, published in 2001, provides a more detailed discussion (Defra, 2001).

[61] In fact, reductions in hazard rate due to reductions in pollution were only applied to people over 30 because only people over 30 were studied in the original studies. However, since mortality rates are low in those under 30, the choice whether or not to include those under 30 probably does not influence the answer to any significant extent.

[62] This might give a small underestimate as a few people do live beyond 100 years.

Figure 2.4

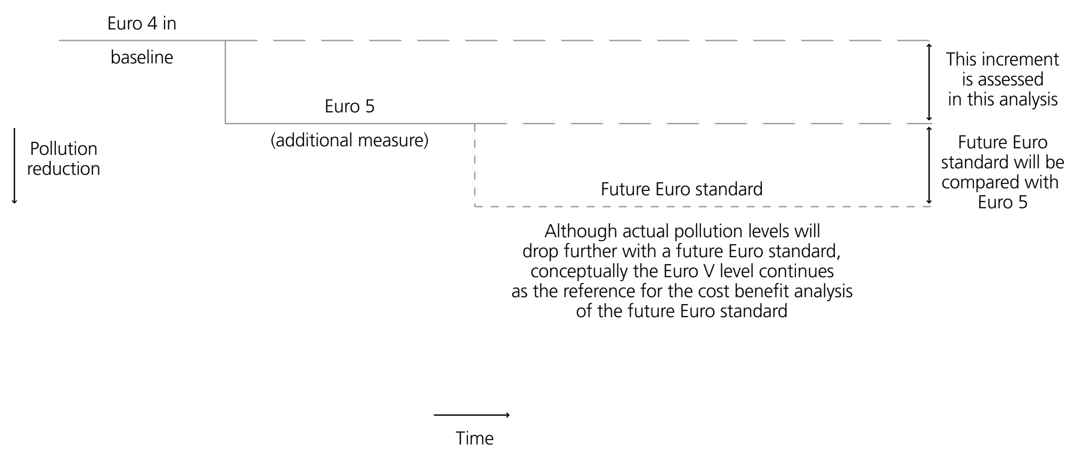
Different durations of pollution reductions



156. Of course, it might be argued that to expect a new measure to last 100 years is unrealistic. However, measures such as Euro 5 standards for cars are only likely to be replaced by more advanced standards. The pollution reduction achieved by these more advanced standards would be compared with the pollution reduction achieved by the original Euro 5 standards. So, in conceptual terms, the pollution reduction achieved by Euro 5 will be maintained long term, with the more advanced standards adding a further incremental reduction that is not considered in the current analysis (See Figure 2.5).

Figure 2.5

Euro standards for cars and long term pollution reductions

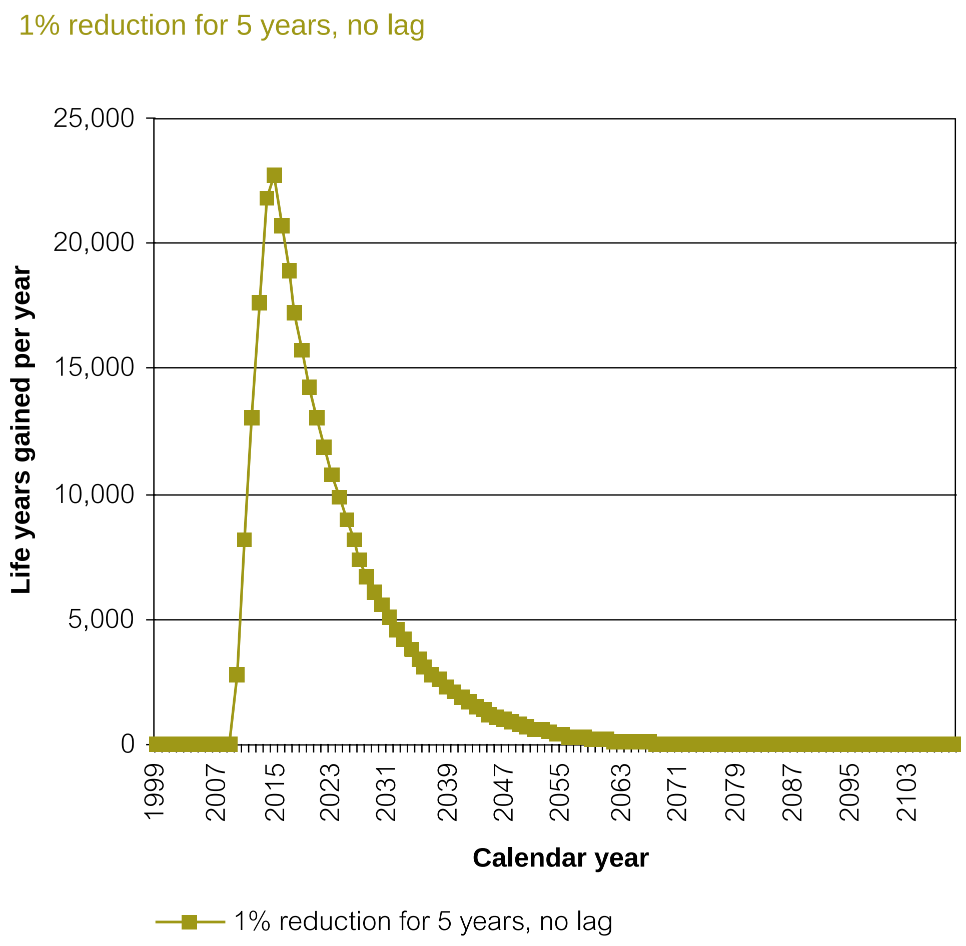


157. There are, however, policy scenarios where a sustained reduction would not be expected to last a lifetime. For example, some policies require abatement equipment to be applied to new power stations but not old ones. If this policy was in the baseline of measures already agreed, then an additional measure examining a requirement for use of abatement equipment on old power stations, would revert to the baseline when the old power stations were closed. In other words, the reduction in pollution from the additional measure would cease. Or there might be a policy to bring in future environmental standards a few years early. To cover these possibilities, calculations were also done for 5 year and 20 year sustained reductions.[63] Finally, calculations were done for an 'annual pulse', a one year reduction in pollution. This was not because there were any policies expected to last for one year only but because the results from a one year reduction can be multiplied up to give an approximation of the results for a variety of policy durations. Figure 2.4 on page 68 summarises the variety of scenarios modelled.

158. It is important to note that even where the policy stops after, say, 5 years, the lifetable still needs to be followed up to 2109. This is because the additional people who survive because of the pollution reduction during the first 5 years will die at various times over the ensuing years. It is the difference in when these deaths occur between the baseline and the 5 year pollution reduction scenario that gives the gain in life years. Some of the gain in life years from the people who survive longer will be missed if the lifetable is stopped early (See Figure 2.6).

[63] See Annex 5 of this report for a breakdown of how each additional measure was modelled.

Figure 2.6



Note: life years gained continue after the first 5 years

2.5.3.10 Lag times

159. The lag time between a reduction in pollution and a reduction in hazard rate is unknown. The HEI reanalysis showed that the relative risk for all cause mortality was similar in those under and over 50 years old. If the lag time was close to or longer than 50 years, an effect in those under 50 would not be expected. COMEAP assumed a lag time of between 0 and 40 years (Department of Health, 2001a). This range has been adopted for this analysis. It is important to realize that neither a lag time of 0 for everyone nor a lag time for 40 years for everyone is likely. It is known from the time series studies that, at least in some cases, the lag time can be less than a year but it is also known that the effect found in the cohort studies is greater than the effect found in the time-series studies. Lung cancer mortality is one of the types of mortality affected by long term exposure, and lung cancer is known to take decades to develop. However, lung cancer is less common than cardiovascular disease, and cardiovascular mortality is the most important effect of long term exposure to particles. The average lag time for all cause mortality is probably somewhere between these two extremes but it is difficult to define where.

160. There is more information on this point than there was when COMEAP came to its conclusions in 2001. For example, a larger reduction in mortality rate than expected from the time-series studies alone occurred in Dublin in the 5 years following a ban on coal sales.[64] This indicates that at least some of the long term effect reflected in the cohort studies can occur in the first few years. It does not rule out a further proportion of the effect occurring later. In its 2006 Interim Statement, COMEAP stated that, although the evidence was limited, its judgement tended towards a noteworthy proportion of the effect occurring in the years soon after pollution reduction rather than later. The 0 to 40 year range has been retained but the above points need to be borne in mind and are discussed further in Chapter 5. Further analysis of lag times, and their impact on the monetised benefits in the cost-benefit analysis, has also been included as part of the recent Monte Carlo analysis presented in section 5.6 of Chapter 5.

2.5.3.11 Method of calculating impacts for different lags

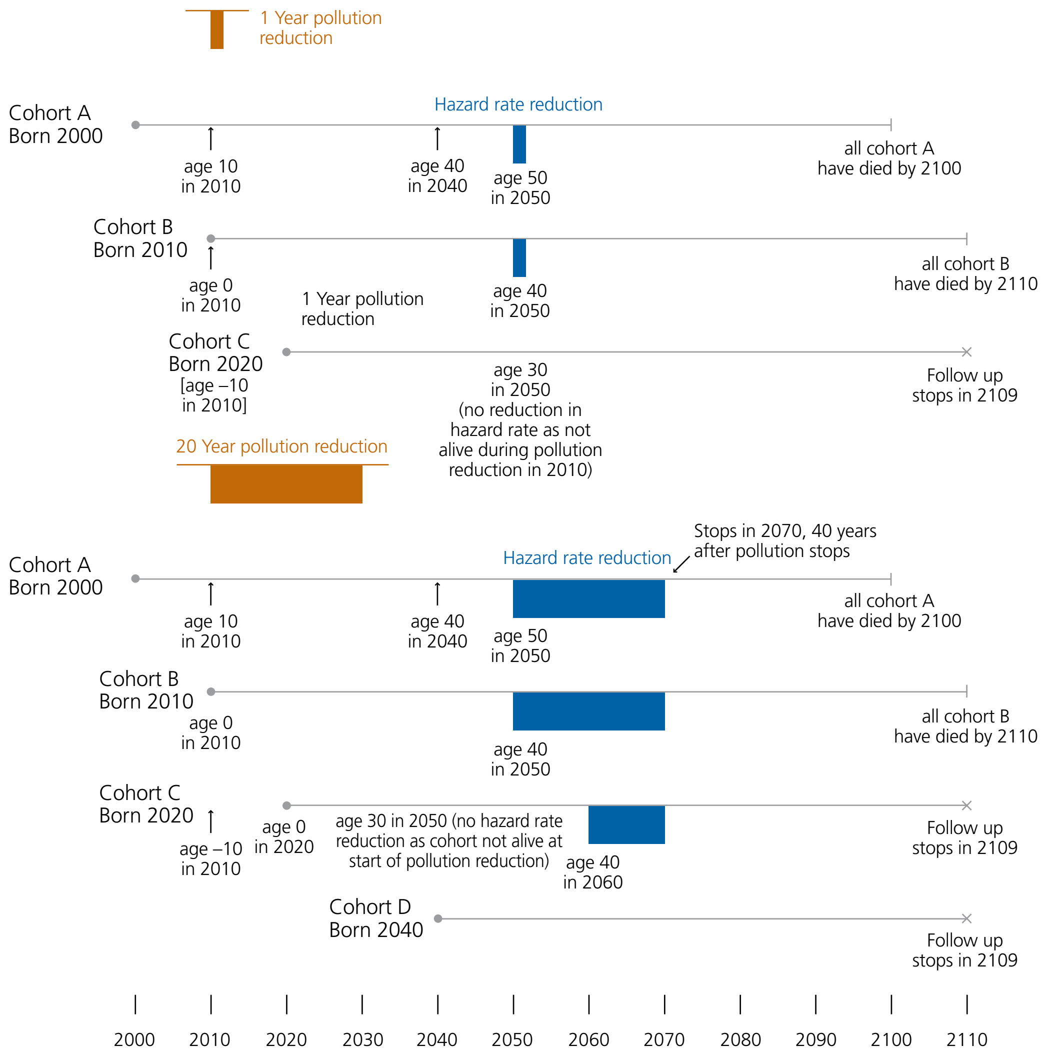
161. Zero lag: for the illustrative 1% reduction in hazard rate, the 0 year lag time is represented by applying the 1% reduction immediately in 2010 and continuing for the appropriate duration (1 year, 5 years, 20 years or 100 years).

162. 40 year lag: the method for calculating the impact assuming a 40 year lag is more complex to explain. It is not the same as simply delaying the application of the hazard rate reduction for 40 years. This point is best explained by referring to Figure 2.7 below. For a 1 year pollution reduction occurring in 2010, the hazard rate reduction would be applied 40 years later in 2050 but not to the whole of the population alive in 2050. This is because some of the population alive in 2050, were not alive in 2010 when the pollution reduction occurred (cohort C in Figure 2.7). In fact, hazard rate reductions would only be applied to those over 40 in 2050. Hazard rate reductions would not occur in those age 40 at earlier dates (cohort A) because 40 years would not have elapsed since the pollution reduction.

64 Clancy et al (2002) 'Effect of Air Pollution Control on Death Rates in Dublin, Ireland: An Intervention Study', Lancet, 360, pp.1210-1214

Figure 2.7

Application of hazard rate reductions – 40 year lag



163. If the pollution reduction is sustained for more than 1 year, cohorts born after the start of the pollution reduction in 2010 will not have the hazard rate reduction applied in 2050 as they were not alive at the start of the pollution reduction (cohort C'). The hazard rate reduction may still be applied at a later date, if the cohort was alive during the sustained reduction and 40 years have elapsed since first exposure in the year of their birth. The hazard rate reduction will still cease 40 years after the end of the pollution reduction (the 40 year lag is a maximum). For cohorts born after the end of the pollution reduction, hazard rate reductions will not apply (cohort D').

164. In summary, the following criteria need to be met for each age group in a particular year:

- 40 years or more to have elapsed since the pollution reduction;
- The age cohort was alive at the time of the pollution reduction;

- 40 years have elapsed since the age cohort's first exposure[65] to the pollution reduction (i.e. only applies to those over 40 since exposure in the years before birth does not count); and
- No more than 40 years have elapsed since the end of the pollution reduction.

2.5.3.12 Results for unit impact factors

165. The paragraphs above have discussed the methods, the different durations and the different lag times. The table below gives the results for the different combinations.

Table 2.7: Unit impact factors for an illustrative 1% reduction in hazard rates – England and Wales[a]

Pollution reduction[b]	Life years[c]	
	No lag	40 year lag
100 year sustained	5,974,449	3,130,384
20 year sustained	1,322,907	1,268,239
5 year sustained	311,938	330,050
1 year pulse	61,457	66,793

[a] For the population alive in 2010 plus new cohorts born up to 2109, followed up until 2109. Comparison of illustrative 1% reduction in hazard rates with 1999 lifetable. Hazard rate reduction applied from 2010 (no lag) for those age 30 and above (see footnote 61) for the various durations shown. For 40 year lag, hazard rate reduction applied according to the criteria in paragraph 164. Other assumptions as in paragraph 153.

[b] Conceptual pollution reduction equivalent to a 1% reduction in hazard rates.

[c] The level of accuracy of the calculations are not as great as the number of significant figures given here but these are retained for the purposes of working through the calculations before rounding the final answers.

166. Table 2.7 shows that shorter durations of hazard rate reductions give smaller totals of life years across the population as would be expected. For the longer durations, the result for the 40 year lag is smaller than for no lag. This is because truncating the calculations at 2109 implies that follow-up is incomplete for a larger proportion of the affected cohorts. For example, for the 100 year sustained result for no lag, hazard rate reductions are applied for the entire 100 year period. For the 40 year lag, no hazard rate reductions are applied for the first 40 years leaving only a 60 year period before the end of follow-up in 2109. For the shorter durations, the 40 year lag result can be larger than the no lag result. Using the 1 year pulse as an example, the hazard rate reduction is only applied for a year for no lag and for a year (but delayed) for the 40 year lag. Further, the underlying mortality rates will be higher in 40 years time as the size of the elderly population increases. The same percentage hazard rate reduction will therefore give a greater gain in life years.

[65] It has been assumed that exposure at any time after birth can have an effect. This assumption is discussed further in Chapter 5 of this report.

2.5.3.13 *Scaling of unit impact factor to the UK*

167. The standard factors apply to the population of England and Wales whereas the particle concentration reductions discussed here apply to the UK as a whole and to other regions. If it is assumed that age distribution and background mortality rates are similar across regions, the unit impact factor can be adjusted by multiplying by the ratio between the relevant national or regional population and the population of England and Wales. (The IOM report has examined the sensitivity of results to changes in baseline rates and found that this did not have much impact. Thus, small differences between regions can be ignored.) For example, the GIS method used by AEA gives the population of England and Wales in 2001 as 51,646,891 and that of the UK in 2001 as 58,279,138. This gives a ratio of the UK to England and Wales population of 1.128. Using this scaling factor, Table 2.8 shows the equivalent unit impact factors for the UK.

Table 2.8: Unit impact factors for an illustrative 1% reduction in hazard rates – United Kingdom[a]

Pollution reduction[b]	Life years[c]	
	No lag	40 year lag
100 year sustained	6,741,659	3,532,373
20 year sustained	1,492,788	1,431,100
5 year sustained	351,996	372,433
1 year pulse	69,349	75,370

a For the population alive in 2010 plus new cohorts born up to 2109, followed up until 2109. Comparison of illustrative 1% reduction in hazard rates with 1999 lifetable. Hazard rate reduction applied from 2010 (no lag) for those age 30 and above (see footnote 61) for the various durations shown. For 40 year lag, hazard rate reduction applied according to the criteria in paragraph 164. Other assumptions as in paragraph 153.

b Conceptual pollution reduction equivalent to a 1% reduction in hazard rates.

c The level of accuracy of the calculations are not as great as the number of significant figures given here but these are retained for the purposes of working through the calculations before rounding the final answers.

2.5.3.14 *Scaling of unit impact factor to actual predicted particle reductions*

168. The unit impact factor(s) derived above can then be scaled to the particular scenarios under examination[66]. The unit impact factors are for an illustrative 1% hazard rate reduction. To derive the appropriate hazard rate reduction for policy measures under consideration, the appropriate coefficient for a percentage hazard rate reduction per $\mu g.m^{-3}$ $PM_{2.5}$ (0.6% for the main analysis) is multiplied by the population weighted mean concentration change for that policy measure. There is not in fact just one population weighted mean concentration change for each policy measure but a representative

[66] Linear scaling is a reasonable approximation for the small coefficients and small concentration changes used in most of the analysis in this report. Where changes are larger, the more precise equation is based on multiplicative scaling of the original study RR (relative risk), taken here as 1.06 for an original concentration change of 10 $\mu g/m^3$. If the new concentration change in population-weighted mean for the policy of interest is $-x$ $\mu g/m^3$ (with a negative sign as the analysis usually concerns reductions), then the new RR is calculated as $1.06^{-x/10}$. The new RR derived can then, as a percentage change, be multiplied by the standard factor to give the desired result.

one was chosen for each policy measure.[67] For long term policy measures, the 2020 population weighted mean was presumed to apply from 2010 for 100 years. For short term measures, the 2010 population weighted mean was presumed to apply from 2010 for a shorter period e.g. 5 or 20 years.

169. The scaling for the actual reduction in particle concentration is analogous to the calculation of short term effects using the population weighted mean concentrations multiplied by the adjusted standard factor (e.g. 0.674 million life years per 1μg.m^{-3} reduction in annual mean $PM_{2.5}$ for a 0.1% hazard rate reduction per μg.m^{-3}) in place of the concentration-response function.

170. The change in population weighted annual mean PM_{10} concentration expected from the additional policies under consideration will be described under each measure in Chapter 3. These policies mainly reduce $PM_{2.5}$ concentrations. It has therefore been assumed that the additional measures to reduce PM_{10} concentrations (expressed as gravimetric concentrations) will reduce $PM_{2.5}$ concentrations by the same number of μg.m^{-3}. (The American studies of the long term effects were based on gravimetric $PM_{2.5}$ data.) The American studies also used medians but work in the UK has shown that, for particles, medians and means are quite similar (Stedman et al, 2002) so COMEAP considered that annual means could be used (Department of Health, 2001a). The further follow-up of the ACS study (Pope et al 2002) used means rather than medians.

171. In summary, for each measure, the appropriate population weighted annual mean $PM_{2.5}$ (gravimetric) is multiplied by:

- The appropriate standard factor of life years per 1% hazard rate reduction for the UK from Table 2.8
- The appropriate coefficient of % hazard rate reduction per 1μg.m^{-3} reduction in annual mean $PM_{2.5}$

172. The same calculation is done for the baseline and subtracted from the above calculation. Calculations are done for both a zero lag and a 40 year lag to give a range for the net gain in life years across the population for the relevant measure and coefficient. In interpreting the results from this range, it should be borne in mind that COMEAP has suggested that a greater proportion of the effect probably involves a lag of only a few years i.e. towards the generally larger result for no lag.[68]

173. A full list of the additional measures considered, and a description of how they are modelled, can be found in Annex 5 of this report.

2.5.4 Quantification sensitivities

174. The main uncertainties include:

- The appropriate size of the coefficient for the long term effects of particles;

[67] The implications of this approximation are discussed further in section 5.3.3.17 of Chapter 5.

[68] Department of Health (2006b).

- The type of particles driving the long term effects;
- The appropriate windows of exposure and lag time for the long term effects of particles;
- Various assumptions used in applying the lifetable methodology;
- Possible long term effects of other pollutants;
- The omission of possible effects on more minor outcomes such as respiratory symptoms;
- Separating the effects of nitrogen dioxide and particles; and
- Effects of long term exposure to pollutants on morbidity.

Not all of these uncertainties will be resolvable. The uncertainties are discussed in more detail in Chapter 5.

2.5.5 Valuation

175. In previous appraisals of air quality policy proposals, it has not been possible to value health impacts due to a lack of empirical evidence as to the appropriate values. Values for a range of health endpoints have now been agreed, following recommendations by the IGCB. The full paper discussing the recommendations is found at Annex 2.

176. The IGCB recommendations drew upon recent research in the area of air quality health impact valuation, particularly the study by Chilton et al (2004).[69] This study had been commissioned by Defra to provide empirical evidence on the willingness to pay to reduce the health impacts associated with air pollution.

177. Following the publication of the Chilton et al (2004) study, Defra held a workshop for expert economists and epidemiologists to discuss the results of this study and an additional study by Markandya et al (2004) which assessed the willingness to pay for reducing mortality risks associated with air pollution.

178. The recommendations on valuation of mortality effects associated with air pollution are based on evidence drawn mainly from these two studies. For the valuation of morbidity effects, the recommendations are drawn from the Chilton et al (2004) study and a study carried out by Pearce et al (1998).

179. The recommendations are summarised in Table 2.9 below.

[69] Chilton et al (2004) 'Valuation of Health Benefits Associated with Reductions in Air Pollution'. Available at http://www.defra.gov.uk/environment/airquality/publications/healthbenefits/index.htm

Table 2.9: IGCB recommended health values

Health effect	Form of measurement to which the valuations apply	Central value (2004 prices)	Sensitivity
Acute Mortality	Number of years of life lost due to air pollution, assuming 2-6 months loss of life expectancy for every death brought forward. Life expectancy losses assumed to be in poor health	£15,000	10% and 15% of life years valued at £29,000 instead of £15,000 (to account for the avoidance of sudden cardiac deaths in those in apparently good health).
Chronic Mortality	Number of years of life lost due to air pollution. Life expectancy losses assumed to be in normal health.	£29,000	£21,700 – £36,200 (sensitivity around the 95% confidence interval)
Respiratory Hospital Admissions	Case of a hospital admission, of average duration 8 days	£1,900 – £9,100	£1,900 – £9,600
Cardiovascular Hospital Admissions	Case of a hospital admission, of average duration 9 days	£2,000 – £9,200	£2,000 – £9,800.

180. While the ability to value the health impacts represents a major step forward in the ability to use CBA to assess air quality policy options, there are a number of uncertainties surrounding the values that need to be taken into account when interpreting the results of the analysis. In particular, there are uncertainties surrounding:

- The amount of life expectancy lost due to the acute effects of air pollution;
- The quality of the life expectancy lost due to the acute effects of air pollution;
- The quality of the life expectancy lost due to the chronic effects of air pollution;
- The ability of respondents within the contingent valuation study to accurately value losses of life expectancy in poor health; and
- The accuracy with which study respondents valued morbidity effects.

181. The sensitivities in the valuation analysis incorporated in Chapter 5 attempt to account for some of the known uncertainties, however, they by no means incorporate all the uncertainties associated with the application of these values. These have been used as part of the recent Monte Carlo analysis presented in section 5.6 of Chapter 5

182. These agreed values have been used to monetise the quantified health impacts described in sections 2.5.1–2.5.4. The values have been converted to 2005 prices, assuming an inflation rate of 2.5%. In subsequent years, the values have been uplifted by 2%. This reflects an assumption that willingness to pay will rise in line with long term economic growth.

183. The monetised benefits have then been discounted using the discount rates described in paragraph 17. The resultant net present value of the benefits has then been annualised to allow for consistent comparison between policies and against costs.

2.5.6 Damage cost methodology

184. As explained in paragraph 15 above, certain policies have been assessed using projected emissions data only, rather than full modelling of population weighted concentrations. The benefit associated with the emission changes between the measures and the baseline have then been valued using sector-specific cost per tonne estimates. These costs per tonne are described as damage costs.

185. The damage costs used in this analysis are presented in Annex 3. This annex has been updated since the Third IGCB report to reflect the new formation rate of secondary particles, the latest recommendations from COMEAP on the use of hazard rates and to reflect the removal of indirect effects from ozone for the NO_X damage costs. In addition, the methodology for the derivation of the damage costs is described in detail in an accompanying report (Watkiss et al, 2006). Damage costs are derived from comprehensive modelling analysis, using the impact-pathway approach i.e using the same approach as for those measures being assessed using the full modelling of population weighted concentrations. They are derived from runs that aim to estimate the marginal benefits of emission changes and incorporate the impacts on human health, materials and crops.

186. The effects included in the damage costs estimates are presented in Table 2.10 below.

Table 2.10: Effects included in damage costs estimates

Burden	Effect
Human exposure to PM_{10}/$PM_{2.5}$ (emitted directly or formed indirectly from NO_2 or SO_2)	Chronic effects on mortality Acute effects on morbidity (respiratory and cardiac hospital admissions)
Human exposure to SO_2 (emitted directly)	Acute effects on mortality and morbidity (respiratory hospital admissions)
Exposure of crops to ozone	Yield loss for barley, cotton, fruit, grape, hops, millet, maize, oats, olive, potato, pulses, rapeseed, rice, rye, seed cotton, soybean, sugar beet, sunflower seed, tobacco, wheat
Damage to materials	Acidic deposition Ozone damage to polymeric materials Building soiling

187. The starting point for the analysis has been the assessment of the baseline conditions, as described in section 2.4 of this chapter, in 2010. The impacts of the baseline are quantified and valued, using the methodology described in sections 2.5.2 to 2.5.5 above.

188. The analysis then looks at marginal emissions reductions, reducing the emissions individually by 10% in each sector, or by a suitable marginal quantity (e.g. 50,000 tonnes). The impact-pathway analysis is re-estimated (changes in emissions, changes in air pollution concentrations, changes in impacts, changes in values) as described in previous sections. The marginal change in values is then divided by the change in emissions (in tonnes) to produce a damage cost. At present it is assumed that the model response to different marginal changes will be linear (i.e. for smaller or larger changes than 10%). This approximation is generally appropriate for primary PM and secondary PM analysis but less so for ozone.

189. The damage costs aim to reflect the marginal damage costs of pollution, i.e. the additional marginal effect of one extra tonne of pollution (or the removal of one extra tonne of pollution). Previous studies have shown that the marginal damage costs of air pollution vary very significantly (per tonne of pollutant emitted) according to a range of parameters including:

- Location of emissions;
- Height of emission;
- Local and regional meteorology and other secondary pollutant precursors; and
- Local and regional receptors (density of receptors and geographical spread).

190. To try and address this, the analysis has used a different approach for different pollutants:

191. For primary particulates (PM_{10}), the analysis has produced separate values for each major sector. This reflects the importance of PM as a local pollutant, and takes into account the stack height and location of emissions (in relation to population density). This is necessary as previous analysis[70] has shown that order of magnitude differences can occur for damage costs from PM_{10} between emissions in different locations from different sources. In summary, areas of higher population density/local population (urban areas) have higher damage costs, because emissions lead to higher population weighted exposure per tonne;

192. For secondary pollutants (secondary particulates), one uniform value has been derived for the UK. This reflects the fact that local issues are less important for these pollutants. These secondary pollutants form in the atmosphere over time, and so the immediate local environment is less important in determining damage costs;

193. In the analysis for the AQS, the 1 year damage costs have been used. These assume that the modelled change in concentration occurs for 1 year only, although the impact on life expectancy is followed up for a 100 year period. These annual damage costs

[70] 'An Evaluation of the Air Quality Strategy' Defra, (2005a). Available at http://www.defra.gov.uk/environment/airquality/strategy/evaluation/report-index.htm

have been used to value the benefits of the short term measures over the timeframe of the policy (5-15 years, depending on the measure). In applying these per tonne estimates to policy measures, the 2005 values have been uplifted by 2% p.a. in future years to reflect the assumption that willingness to pay increases in line with economic growth. The change in emissions in each year have then been valued using the appropriate annual damage costs.

194. As with the scenarios that have been modelled on concentration data, all results are shown as annualised figures.

2.6 Non-health benefits

195. There are a number of non-health benefits that have been quantified and valued as part of the monetary CBA. The methodology associated with these effects is described in more detail in this section.

2.6.1 Direct effects of ozone on crop yields

196. Ozone is recognised as the most serious regional air pollution problem for the agricultural and horticultural sectors. The analysis in this review has directly quantified the changes in crop yields in the UK and valued these using international crop prices.

197. The approach adopted for the analysis of methods in this area has been informed particularly by the Integrated Cooperative Programme (ICP) on Vegetation, and ICP/MM (Mapping and Modelling).[71] The approach has linked changes in ozone concentrations with data on the stock at risk,[72] and exposure-response functions for assessment of crop impacts from ozone.[73]

198. The valuation of impacts on agricultural production is reasonably straightforward, with estimated yield loss being multiplied by world market prices as published by the UN's Food and Agriculture Organisation. World market prices are used as a proxy for the real economic cost on the grounds that they are less influenced by subsidies than local European prices (in other words, they are closer to the 'real' price of production).

199. Some air pollutants other than ozone have been linked in the literature to crop damage (e.g. SO_2, NO_2, NH_3), but generally at higher levels than are currently experienced in the UK. Therefore it is assumed that the direct impact of these other pollutants on agriculture is likely to be small; they have therefore not been quantified and valued. Note however that these pollutants may have indirect effects, for example by stimulating the performance of insects and other agricultural pests, enabling them to impact more severely on crop yield than in the absence of air pollution.

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71 ICP/MM (2004) 'Mapping Manual Revision', United Nations Economic Commission for Europe, ICP Mapping and Modelling. Available at http://www.oekodata.com/icpmapping/html/manual.html

72 The stock at risk database has been developed by the Stockholm Environment Institute (SEI) in York and used in past analysis for ICP Vegetation.

73 Exposure-response functions for assessment of crop impacts from ozone take two forms. The first, sometimes called a Level I approach, relates yield change to ozone concentration, typically expressed as AOT40, the accumulated exposure to ozone in excess of 40ppb during the growing season, measured in units of ppb.days. The second type of relationship, sometimes referred to as a Level II approach, seeks to equate yield change not simply to concentration, but to pollutant uptake, by accounting for crop development and climatic conditions. Quantification based on a Level II approach will be possible only later in 2005, drawing outputs of Defra's ICP Vegetation Contract held by CEH Bangor.

2.6.2 Materials damage from SO_2

200. The analysis of damages to materials in utilitarian applications, i.e. in modern houses, factories, etc. has been well advanced through work by the Europe-wide ICP Materials[74] and quantification under various studies for the European Commission DG Research, particularly ExternE and associated projects. These studies have shown that the pollutants most implicated in acid damage are SO_2 most importantly), H^+ and then NO_2. The most significant impacts are on natural stone and zinc coated materials. A methodological approach exists for the quantification and valuation of material damage, based around the 'impact-pathway' approach linking exposure-response relationships, the stock at risk, and building repair values.

201. Previous analysis has shown low levels of benefits for current air quality policies, due to the progress in reducing SO_2 concentrations (the main pollutant of concern). A number of policies, notably targeting the industrial, domestic and marine sectors, do however lead to reductions in SO_2. The benefits in reducing material damage for these scenarios has been quantified using pollution benefits from previous analysis as part of the Air Quality Strategy Evaluation study.[75]

2.6.3 Materials damage from ozone

202. Although ozone is a major determinant of the lifetime of many rubber materials exposed to the ambient air, only two UK studies have investigated the problem from an environmental perspective. Lee et al (1996)[76] estimated annual damages to the UK of £170 to £345 million for impacts on surface coatings (paints) and elastomers and the cost of anti-ozonant protection used in rubber goods. These estimates were based on US data from the late 1960s, demonstrating the dearth of information in this area. Lee's work served as a scoping study for a larger project (Holland et al, 1998)[77] that undertook experimental assessments of a range of paints, representative of those in use in the UK market, and rubber formulations.

203. The analysis on paint found it unlikely that there would be significant ozone-induced damage during the expected service lifetime of the paint, though the possible effects of interactions of ozone with other environmental stresses in damaging paints were not addressed. In contrast, damage to rubber goods from ozone exposure in the UK was estimated at between £35 to 189 million, with a best estimate of £85 million/year. The effect of a population weighted 1ppb change in ozone was estimated at £3.7 million/year. This estimate has been used to make a approximate estimate of ozone damage to rubber products for the review work.

2.6.4 PM buildings soiling

204. Soiling of buildings by particles is one of the most obvious signs of pollution in urban areas. The factors which can affect the degree of soiling are well known and include: the blackness per unit mass of smoke; the particle size distribution; the chemical

[74] ICP Materials (2003) 'Dose-response functions'. Available at http://www.corr-institute.se/ICP-Materials/html/dose_response.html

[75] 'An Evaluation of the Air Quality Strategy' Defra, (2005a). Available at http://www.defra.gov.uk/environment/airquality/publications/stratevaluation/index.htm

[76] Lee et al (1996) 'The Potential Impact of Ozone on Materials', Atmospheric Environment, 30, pp.1053-65

[77] Holland et al (1998) 'The Effects of Ozone on Materials', Contract report for the Department of the Environment, Transport and the Regions.

nature of the particles; substrate-particle interfacial binding; surface orientation; and micro-meteorological conditions.

205. Different types of particulate emission have different soiling characteristics. For example, diesel emissions have a much higher soiling factor relative to petrol or domestic coal emissions factors due to their particulate elemental carbon (PEC) content.[78] Diesel emissions are the main source of atmospheric PEC in Western Europe. Secondary particulates are not considered to be involved in soiling – the effect is in relation to primary particulate emissions only.

206. Although soiling damage has an obvious cause and effect, the quantification of soiling damage is not straightforward. For the analysis, a number of different approaches and functions have been considered. A model proposed by Pio et al. (1998) has been considered,[79] but the function has proved difficult to implement in practice. As a result, a simplified approach is often used that quantifies soiling damage based on cleaning costs (in the absence of willingness to pay data). Rabl et al (1998)[80] extended this to quantify total soiling costs (i.e. the sum of cleaning cost and amenity loss), and Rabl's work has been used as the basis for quantification of soiling damage.

2.6.5 Social cost of carbon

207. Many of the measures being assessed within this review could have an effect on greenhouse gas emissions. Given the need to address the synergies and trade-offs between air quality and climate change policies, the impacts of measures on carbon emissions have also been assessed, where possible.

208. For long term measures that are assumed to have a perpetual, sustained impact on emissions, the 2020 impact on carbon emissions is assumed to apply between 2010 and 2109; for policies expected to have an impact of less than 20 years, the 2010 impact on carbon emissions is assumed to apply for the lifetime of the policy. Annex 5 provides a list of additional policy measures considered and sets out how each of them are modelled.

209. The tonnes of carbon emitted have been valued according to current interdepartmental guidelines. The central analysis uses a value of £70/tC (2000 prices), uplifted by £1 p.a. thereafter. The sensitivity analysis uses the recommended range of £35/tC – £140/tC. These values have been re-valued to 2005 prices using an estimated inflation rate of 2.5% p.a.

210. The Stern Review 2006[81] suggested that the current treatment of carbon significantly undervalued the cost of carbon. The review suggested a cost of $85 per tonne of CO_2 roughly equating to £240 per tonne of carbon and that carbon emissions should be appraised using a near-zero discount rate on the grounds of intergenerational equity. Further discussion is currently taking place across government departments reviewing

[78] QUARG (1993) 'Urban Air Quality in the United Kingdom. First Report of the Quality of Urban Air Review Group', prepared for the Department of the Environment.

[79] Pio et al (1998) 'Atmospheric Aerosol and Soiling of External Surfaces in an Urban Environment', Atmospheric Environment, 32, pp.1979-89.

[80] Rabl et al (1998) 'Air Pollution and Buildings: An Estimation of Damage Costs in France', Environmental Impact Assessment Review.

[81] Available at http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/stern_review_report.cfm

the social cost of carbon guidance in light of the Stern Review's recent publication. A sensitivity on the cost of carbon has however been presented in section 5.4.

2.7 Costs

211. Many of the assumptions on costs are specific to the individual measures. These are presented and discussed in detail Chapter 3. This section, therefore, focuses on general methodological issues with regards to costs.

212. Costs have been presented in terms of the impact to society as a whole and therefore do not take account of transfers between different sectors (e.g. taxes and subsidies) or accounting costs such as depreciation.

213. The costs are presented in 2005 prices and have been adjusted for inflation, assuming a rate of 2.5% p.a. As with benefits, costs have been discounted using current HM Treasury Green Book guidelines.

214. For industrial and domestic-related measures, both capital costs, such as those associated with the fitting of selective catalytic reduction, and changes to operating costs are included. The assessment of transport-related costs takes account of the costs of new technology, the resource costs due to a change in fuel use and the welfare effect due to any change in kilometres travelled for most transport measures. Therefore, as far a possible, the costs include both financial costs and wider welfare impacts.

215. Costs have been assessed over the same timeframes as the benefits:

- For policies expected to deliver a perpetual, sustained improvement in air quality, costs have been assessed over 100 years. Costs have been estimated year on year between the start of the policy and 2020 and then extrapolated up to 2109. For the central analysis, the extrapolation allows for anticipated increases in fuel prices and the social cost of carbon but otherwise assumes that costs are maintained at their 2020 level in future years.
- For short term policies, costs have been estimated year-on-year over the relevant timeframe. This is discussed in more detail in Chapter 3.

216. To aid comparison between measures that have different timescales, all costs are presented on an annualised basis.

217. There is considerable uncertainty surrounding the cost estimates. New technology, new processes and structural changes to the economy may all impact the future costs of policy implementation. In most instances, it is impossible to predict such changes with any level of accuracy. In the recent Evaluation study,[82] it was found that, in the majority of cases, actual costs associated with the implementation of air quality policies, were lower than costs that had been predicted prior to implementation. This would suggest that regulation can spur innovation, and that the CBA may not adequately predict the

[82] 'An Evaluation of the Air Quality Strategy' Defra (2005a). Available at http://www.defra.gov.uk/environment/airquality/publications/stratevaluation/index.htm

impact of innovation on costs. For some measures, a range of costs has been used reflecting different underlying assumptions about the costs and these are presented in the central analysis. For other measures, where there is a higher level of uncertainty about the costs, sensitivity analysis has been presented in Chapter 5. That chapter also demonstrates the sensitivity of the overall CBA results to changes in costs more generally.

2.8 Presentation of results: explanation of results format and baseline results

2.8.1 Format for the presentation of results

218. Given the many different, uncertain factors that influence both the quantification and valuation of air quality impacts, it is difficult to present the results for each measure in a succinct format. To aid comparison between the results a consistent format has been adopted in Chapter 3. This is described in more detail in this section.

219. Emission or concentration results are shown for each measure. For those measures modelled at concentration levels, the effect of the measure on the population weighted mean concentrations of PM_{10}, NO_2 and ozone is shown in $\mu g.m^{-3}$ for the years 2010, 2015 and 2020 for each devolved administration. For those measures assessed using emissions only the change in PM_{10}, NO_2 and ozone emissions (in tonnes) is shown for the years 2010, 2015 and 2020 for the UK. A negative number (shown in parentheses) reflects a drop in concentrations or emissions; a positive number reflects an increase.

220. The summary of physical impacts presents:

- PM life years saved – 6%.[83] Shows the chronic mortality impacts of changes in PM_{10} in terms of life years saved, assuming a 6% concentration-response coefficient. The range represents the effect of different assumptions regarding lags: the lower bound assumes a 40 year lag between the change in PM_{10} and the change in mortality; the upper bound assumes no lag between the change in PM_{10} and the change in mortality. Note that recent advice suggests results towards the shorter lags ie. towards the upper bound may be more likely (see section 2.5.3.10);
- PM – RHA. Shows the impact on respiratory hospital admissions as a result of changes in PM_{10} concentrations;
- PM – CHA. Shows the impact on cardiovascular hospital admissions as a result of change in PM_{10} concentrations;
- SO_2 – mortality. Shows the acute mortality impacts of changes in sulphur dioxide concentrations. Note that this relates to the direct effects of SO_2 as a gas rather than the effects of SO_2 as a precursor of sulphate. The latter is covered under the PM health effects. This impact is only shown for those measures with the biggest expected effect on SO_2 concentrations;

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[83] The central analysis presented in Chapter 3 has been updated to reflect COMEAP's recommendation of a 0.6% hazard rate per $\mu g.m^{-3}$ $PM_{2.5}$ (6% per 10$\mu g.m^{-3}$) in its 2006 Interim Statement. As such only results using a 6% hazard rate reduction have now been included. Further consideration of the sensitivities around this estimate have been included in Chapter 5.

- SO_2 – RHA. Shows the impact on respiratory hospital admissions of changes in sulphur dioxide concentrations. Note that this relates to the direct effects of SO_2 as a gas rather than the effects of SO_2 as a precursor of sulphate. The latter is covered under the PM health effects. This impact is only shown for those measures with the biggest expected effect on SO_2 concentrations;
- Ozone mortality. Shows the acute mortality impacts of changes in ozone concentrations. The lower bound of the range assumes a 50ppb threshold effect for ozone; the upper bound of the range assumes zero threshold effect for ozone;
- Ozone – RHA. Shows the impacts on respiratory hospital admissions as a result of changes in ozone concentrations. The lower bound of the range assumes a 50ppb threshold effect for ozone; the upper bound of the range assumes zero threshold effect for ozone; and
- Carbon. Shows the tonnes of carbon saved.

221. The chronic mortality impacts are presented as life years saved over the life time of the policy, followed up over a 100 year period. Figures for life years are shown rounded to the nearest thousand[84]. All other impacts are shown on an annual basis: for those policies considered to have a sustained impact on air quality, the 2020 estimate is presented; for shorter term policies, the 2010 estimate is presented. For all impacts positive figures represent a benefit e.g. life years saved or a reduction in hospital admissions; negative figures (shown in brackets) represent a disbenefit e.g. an increase in hospital admissions or tonnes of carbon.

222. The annual present value (PV) of benefits from each measure shows:

- Valued health effects: all of the health effects described in the previous paragraph have been valued using the central estimates in Table 2.9;
- Carbon: the carbon impacts, valued using the current recommendations on the social cost of carbon;
- Crops: shows the valued impact of ozone on crops yields; and
- Buildings: includes the valued impact of the materials damage from SO_2, ozone and PM buildings soiling.

Positive figures represent a benefit; negative figures represent a disbenefit.

223. The costs table for each measure shows the relevant cost information, including:

- Resource costs such as the cost of additional fuel;
- Technology costs;
- Welfare impacts;

[84] The many uncertainties involved should be borne in mind when interpreting small differences between the figures and more weight should be given to clear large differences. Variations in the figures due to uncertainties are discussed further in Chapter 5.

- Lifetime of the technology: shows the (assumed) useful lifetime of the assets required to implement the measure;
- Capital cost: shows the capital investment required;
- Operating cost: shows the annual operating cost associated with any new capital investment; and
- PV of costs: shows the annual present value of costs

224. Annual costs and benefits shows the annual present value (PV) of costs and benefits and the resultant annual net present value (NPV):

- Annual PV of costs: repeats the annual present value of costs from the cost table.
- Annual PV of benefits: Shows the annual present value of all health and non-health benefits, assuming a 6% concentration-response coefficient for the PM chronic mortality impacts. The lower bound of the range assumes the lowest estimate for each element of the benefits, the upper bound assumes the highest estimate for each element of the benefits.
- Annual NPV: The lower bound assumes the lowest estimate for each element of the benefits and the highest estimate for the costs; the upper bound assumes the highest estimate for each element of the benefits and the lower estimate for costs.

Positive figures represent a benefit; negative figures represent a cost.

2.8.2 Results from the baseline

225. The baseline is used for comparative purposes to assess the impact of the additional measures. It includes all current policies and agreed and planned future policies and therefore the baseline itself results in changes to pollutant concentrations and associated health impacts over time. The sections below express the comparison with the baseline in three ways:

- The average loss of life expectancy in a birth cohort from total levels of anthropogenic $PM_{2.5}$
- The total life years lost across the whole population from total levels of anthropogenic $PM_{2.5}$
- The total life years gained across the whole population from the reduction between the level in 2005 and 2020 levels (with or without additional measures), with the $PM_{2.5}$ difference represented by the difference in PM_{10} for comparison with the results in the main analysis.

More details on the reasons for the different approaches are given in the paragraphs below.

2.8.2.1 Average loss of life expectancy from total current or projected baseline levels of anthropogenic $PM_{2.5}$

226. Although this report is predominantly concerned with assessing the benefits and costs

of changes in pollutant concentrations as a result of particular policies, there is an interest in the overall health impact of air pollution. The dominant component of this overall health impact is the effect of current levels of particles on life expectancy. This is discussed in the section below.

227. When considering an absolute level of health impact it is not appropriate to use PM_{10} modelling.[85] The calculations below are, therefore, based on $PM_{2.5}$ modelling.[86] In addition, it might be considered unrealistic to reduce current levels of particles to zero, when not all particles in the air are anthropogenic. The level of non- anthropogenic $PM_{2.5}$ is assumed to be constant and is estimated to be about 3.37µg.m^{-3} annual average population-weighted mean.[87] This has been subtracted from the modelled $PM_{2.5}$ population-weighted mean in 2005 and in 2020 after the baseline agreed measures to give the anthropogenic $PM_{2.5}$ (see Table 2.11 below). For comparison, the modelled anthropogenic $PM_{2.5}$ population-weighted mean is also shown for 2020 after a package of the additional measures[88] considered in Chapter 3 have been implemented.

Table 2.11: $PM_{2.5}$ UK population-weighted mean (Total and Anthropogenic)

Date	$PM_{2.5}$ annual average population-weighted mean (gravimetric, µg.m^{-3})	Anthropogenic $PM_{2.5}$ annual average population-weighted mean (gravimetric, µg.m^{-3})
2005	13.514	10.144
2020 baseline agreed measures	10.680	7.310
2020 with additional measures (Measure R)	10.016	6.646

228. The most easily interpretable way to calculate the loss of life expectancy as a result of current exposure to man-made fine particles in 2005 is for those born in 2005 and exposed for the whole of their lifetimes. The results for 2005 and 2020 are shown in Table 2.12. Based on the latest COMEAP recommendation,[89] it is estimated that the average loss of life expectancy would be around 7.5 months in 2005 with low and high sensitivities of about 5 weeks and about 14 months. With the implementation of measures already agreed, this is predicted to drop to around 5.5 months in

[85] An absolute level of PM_{10} will include coarse particles, whereas a policy-induced change in PM_{10} is predominantly a change in the $PM_{2.5}$ component. As PM_{10} modelling is generally more robust than $PM_{2.5}$ modelling, changes in the former were used in the main analysis of policy-induced changes. The HEI reanalysis (Health Effects Institute, 2000) has shown that $PM_{2.5}$ is more strongly associated with long term effects than PM_{10}.

[86] See section 5.3.3.9 in Chapter 5 for further discussion comparing results using PM_{10} and $PM_{2.5}$ modelling.

[87] Using the coefficients from the ACS study to calculate the impacts of reductions in the $PM_{2.5}$ levels from the total current level to the non-anthropogenic level of 3.3µg.m^{-3} involves extending the calculation outside the range of the ACS study (the lowest concentration given in the HEI reanalysis was 9µg.m^{-3}). This adds an element of uncertainty to the calculations presented here.

[88] This combined package (Measure R) is described in section 3.4 of Chapter 3.

[89] The main hazard rate reduction used was 0.6% per µg.m^{-3} $PM_{2.5}$ and a range of lag times from 0 to 40 years. Current advice suggests that the lower end of the range of lag times is more likely (the upper end of the range of results for each hazard rate reduction shown in Table 2.12). The low and high sensitivities for the hazard rate reduction (0.1% and 1.2% per µg.m^{-3} $PM_{2.5}$) represent 'typical' low and 'typical' high values rather than the full uncertainty range. See section 5.3.3.7 of Chapter 5 for a fuller discussion. The size of the concentration change, in combination with a 1.2% hazard rate reduction meant that a more precise non-linear equation was needed to scale the results (see footnote 66). For consistency, this equation was used for the 0.6% and 0.1% hazard rate reductions as well in this section.

2020, with low and high sensitivities of around 3.5 weeks and 10 months. With the implementation of a package of additional measures, it is predicted to drop further to around 5 months with low and high sensitivities of around 3.5 weeks and around 9 months. As with any average, the loss of life expectancy will be greater than this for some people and less than this for others.

Table 2.12: Estimated loss of life expectancy for a birth cohort[a] (combined male and female) from total current or projected levels of anthropogenic $PM_{2.5}$

	Main result	Sensitivity	
Date	**0.6%[b]**	**'typical low' (0.1%)[c]**	**'typical high' (1.2%)**
2005	203 – 210 days[d] (7 to 7.5 months)	34 – 36 days (about 5 weeks)	396 – 410 days (14 – 14.5 months)
2020 (baseline agreed measures)	146 – 152 days (5 to 5.5 months)	25 – 26 days (about 3.5 weeks)	285 – 295 days (10 – 10.5 months)
2020 with additional measures (Measure R)	133 – 138 days (about 5 months)	23 – 24 days (about 3.5 weeks)	259 – 269 days (9 – 9.5 months)

[a] 2005 and 2020 starting birth cohort assumed to be as in 1999. Birth cohort followed to extinction. Average loss of life expectancy result is independent of birth cohort size. Calculations were done for males and females separately but the results were very close, differing by only 5 days at most. Combined averaged results for males and females together are shown here.

[b] Coefficients per $\mu g.m^{-3}$ $PM_{2.5}$ as recommended by COMEAP (Department of Health 2006b, 2007).

[c] Sensitivities as recommended by COMEAP (Department of Health 2007). See section 5.3.3.7 of Chapter 5 for further discussion.

[d] For a 40 year lag (lower end of range) or no lag (upper end of range). The interim statement by COMEAP (2006b) suggests that, although the evidence is limited, the evidence tends toward a greater proportion of the effect occurring in the first few years after a pollution reduction i.e. a shorter lag towards the upper end of the range.

Total life years lost from total current or projected levels of anthropogenic $PM_{2.5}$

229. Of course, the people exposed to current levels of anthropogenic $PM_{2.5}$ are not only those born in 2005 or 2020 but also people of other ages. These other age groups will not be exposed to the specified anthropogenic $PM_{2.5}$ concentration for the whole of their lives, nor will the loss of life years be counted for the whole of their lives. The older age groups will have had part of their lives before the lifetable follow-up starts and age groups born after the start of lifetable follow-up will continue their lives after follow-up ceases. Therefore, the average loss of life years within each of these other age groups, within the period of lifetable follow-up, will be less than that for the birth cohort above. Nonetheless, the smaller loss of life years within each of these other age groups is additive to those in the birth cohort. For this reason, although it is a less familiar concept, a more complete result is given if the answers are expressed in terms of total life years lost across the population.

230. The results in terms of total life years are given in the table below. This table shows that current levels of man made fine particulate air pollution has a marked impact on life years lost, that this will be reduced with the baseline agreed measures by 2020 but that a reasonable impact still remains. (Note that, although the results are in millions of life years and appear extremely large, the results do represent accumulated life years lost over the entire population, including new birth cohorts, for an extended 100 year period. The total life years lived by the population in this period is about 5 billion). The remaining impact is reduced after implementation of a package of additional measures (Measure R) discussed in Chapter 3.

Table 2.13: Estimated total life years lost across the UK population from total current or projected levels of anthropogenic $PM_{2.5}$

	Main result	Sensitivity	
Date	**0.6%[a]**	**'typical low' (0.1%)[b]**	**'typical high' (1.2%)**
2005	20.3 – 38.7 million life years	3.5 – 6.8 million life years[c]	38.4 – 73.2 million life years
2020 (baseline agreed measures)	14.7 – 28.1 million life years	2.6 – 4.9 million life years	28.1 – 53.6 million life years
2020 with additional measures (Measure R)	13.4 – 25.6 million life years	2.3 – 4.4 million life years	25.6 – 48.9 million life years

a Coefficients per $\mu g.m^{-3}$ $PM_{2.5}$ as recommended by COMEAP (Department of Health 2006b, 2007).

b Sensitivities as recommended by COMEAP (Department of Health 2007). See section 5.3.3.7 of Chapter 5 for further discussion.

c For a 40 year lag (lower end of range) or no lag (upper end of range). The interim statement by COMEAP (2006b) suggests that, although the evidence is limited, the evidence tends toward a greater proportion of the effect occurring in the first few years after a pollution reduction i.e. a shorter lag towards the upper end of the range.

231. These estimates of total life years have then been used to value the absolute cost of air pollution in the UK. The total number of life years shown in Table 2.13 above have been used to scale the standard lifetable runs; the life years lost in each year (between 2010 and 2109) have then been valued as described earlier in the chapter. The valuation of total impacts is subject to a great deal of uncertainty; for example, since the standard lifetable runs estimate life years lost between 2010 and 2109, the valuation of the 2005 baseline effects does not incorporate the impact between 2005 and 2009 and is therefore likely to be an underestimate. Likewise, the valuation of the 2020 baseline effect is likely to be an overestimate since it includes impacts in the years between 2010 and 2019.

232. The results of the valuation of total life years are shown in Table 2.14 below. It is recommended that future work is undertaken to improve the methodology for the valuation of the overall health impact of air pollution.

Table 2.14: Estimated value of overall health impact from total current or projected levels of anthropogenic $PM_{2.5}$ (£m p.a.)

	Main result	Sensitivity	
Date	**0.6%**	**'typical low' (0.1%)**	**'typical high' (1.2%)**
2005	8,582 – 20,165	1,502 – 3,528	16,238 – 38,115
2020 (baseline agreed measures)	6,235 – 14,651	1,084 – 2,546	11,888 – 27,933
2020 with additional measures (Measure R)	5,680 – 13,346	986 – 2,316	10,848 – 25,490

2.8.2.2 Total life years gained based on changes in PM_{10} for the pollution reduction produced by the baseline (agreed measures)and by a package of additional measures

233. The above results for the baseline were given in terms of the absolute impact of anthropogenic $PM_{2.5}$ in 2005 and in 2020 after the baseline agreed measures had been implemented. The benefits derived from the implementation of the measures agreed in the baseline can also be calculated by looking at the **change** (reduction) in $PM_{2.5}$ which occurs as a result of the agreed measures. This change is, by definition, anthropogenic. As discussed earlier (see paragraph 104), the change in modelled PM_{10} can be assumed to be approximately the same as a change in $PM_{2.5}$ as almost all of the changes in particulate concentrations produced by the policies occur in the $PM_{2.5}$ fraction of PM_{10}. As PM_{10} modelling is more robust, this is the approach that has been used in the main analysis.

234. The table below shows that the measures already agreed in the baseline are projected to deliver around a $3 \mu g.m^{-3}$ reduction in PM_{10} as a UK population-weighted mean. The vast majority of this change is expected to be due to a reduction in $PM_{2.5}$ concentrations.

Table 2.15: Change in concentrations by implementing the baseline agreed measures for the UK, disaggregated by country

Country	Pollutant	Concentration changes relative to 2005 ($\mu g.m^{-3}$)[a b]		
		2010	**2015**	**2020**
England	PM_{10}	(1.761)	(2.616)	(3.219)
	NO_2	(3.654)	(5.646)	(6.518)
	Ozone	0.237 – 5.137	0.607 – 7.890	1.054 – 10.119
Northern Ireland	PM_{10}	(1.364)	(1.715)	(1.493)
	NO_2	(2.275)	(3.564)	(4.145)
	Ozone	0.050 – 2.461	0.332 – 4.002	0.675 – 5.426
Scotland	PM_{10}	(1.050)	(1.508)	(1.735)
	NO_2	(2.749)	(4.307)	(4.845)
	Ozone	0.104 – 3.241	0.365 – 5.066	0.740 – 6.672
Wales	PM_{10}	(1.454)	(2.099)	(2.559)
	NO_2	(2.923)	(4.487)	(5.277)
	Ozone	0.165 – 3.524	0.613 – 5.802	1.229 – 7.951
UK	PM_{10}	(1.674)	(2.470)	(3.011)
	NO_2	(3.502)	(5.416)	(6.247)
	Ozone	0.217 – 4.818	0.607 – 7.434	1.054 – 9.583

[a] Ozone concentration changes shown as a range incorporating results assuming both a zero threshold and a 50ppb threshold. PM_{10} concentrations are presented in ($\mu g.m^{-3}$, gravimetric).

[b] Ozone concentration changes shown relative to 2003 not 2005 (2005 not modelled)

235. For comparison, a package of additional measures (Measure R) is projected to deliver a further 0.926 $\mu g.m^{-3}$ reduction in PM_{10} as a UK population-weighted mean by 2020. Again, the vast majority of this change is expected to be due to a reduction in $PM_{2.5}$ concentrations. The population-weighted concentration changes associated with this measure are shown in Table 3.134 in Chapter 3.

236. Table 2.17 below summarises the major health impacts that result from the changes in baseline concentrations between 2005 and 2020. The difference between the projected concentration in 2020 and the concentration if 2005 concentrations had remained unchanged (about 3μg.m^{-3}) is assumed to be representative of the concentration difference between 2010 and 2109 as described earlier in the methodology section.

Table 2.17: Baseline health impacts relative to 2005[a b c]

Region	PM life years saved (000s) – 6% (2010-2109)[d]	PM – RHA (2020, p.a.)	PM – CHA (2020, p.a.)	Ozone mortality (2020, p.a.)	Ozone RHA (2020, p.a.)
2020 (Baseline)	6,381 – 12,178	1058	1060	(3316) – (355)	(3830) – (410)

[a] For comparison with Measure R below and with the main analysis, linear scaling has been used in this table. This overestimates the benefits by about 4%.

[b] Data presented in the table in brackets represents a negative impact – for ozone impacts this reflects the increase in population weighted ozone concentrations presented in the previous table.

[c] Ozone concentration changes shown relative to 2003 not 2005 (2005 not modelled)

[d] Sensitivities 'typical low' (1%) 1,063-2,030 thousand life years saved, 'typical high' 12,762 – 24,356 thousand life years saved. These representative low and high values do not represent the full uncertainty range. With non-linear scaling these figures would be about 0.5% lower for the 1% coefficient and about 8% lower for the 12% coefficient. For a further discussion on the sensitivities see section 5.3 of Chapter 5.

237. For comparison, the results for Measure R, compared to the 2020 baseline, are shown in Table 2.18 below.

Table 2.18: Further health impacts of implementing combined Measure R relative to 2020 baseline[a b]

	PM life years saved (000s) – 6% (2010-2109)[c]	PM – RHA (2020, p.a.)	PM – CHA (2020, p.a.)	Ozone mortality (2020, p.a.)	Ozone RHA (2020, p.a.)
2020 additional measures (Measure R)	2,020 – 3,805	325	326	(364) – 6	(421) – 7

[a] For comparison with Measure R below and with the main analysis, linear scaling has been used in his table. This overestimates the benefits by about 3%.

[b] Data presented in the table in brackets represents a negative impact – for ozone impacts this reflects the increase in population weighted ozone concentrations.

[c] Sensitivities 'typical low' (1%) 337 – 634 thousand life years saved, 'typical high' 4,040 – 7,610 thousand life years saved. These representative low and high values do not represent the full uncertainty range – see section 5.3 of Chapter 5 for further discussion. With non-linear scaling these sensitivity results would have been about 0.5% and 6.5% lower for the 1% and 12% coefficients respectively. Full results for non-linear scaling are given in the sensitivity analysis results table available from www.defra.gov.uk.

238. The values associated with the change in health impacts due to the change in baseline concentrations between 2005 and 2020 are shown in Table 2.19 below.

Table 2.19: Baseline major health values (£m p.a.)

	PM life years saved – 6%	PM – RHA	PM – CHA	Ozone mortality	Ozone RHA
2020 (Baseline)	2,701 – 6,347	3 – 16	4 – 16	(47) – (2)	(58) – (1)

239. Again, for comparison, the results for Measure R, compared to the 2020 baseline, are shown in Table 2.20 below.

Table 2.20: Estimated major health values of implementing Measure R relative to 2020 baseline (£m p.a.)

	PM life years saved – 6%	PM – RHA	PM – CHA	Ozone mortality	Ozone RHA
2020 additional measures (Measure R)	886 – 2,039	1 - 5	1 – 5	(5) – 0.02	(5) – 0.02

240. It can therefore be seen that the measures already agreed to be implemented between now and 2020 are projected to save around 6.4 to 12.2 million life years[90] across the UK population followed-up over a 100 year period. These impacts are valued at between £2,701m p.a. and £6,347m p.a. This can be compared with the results for the various additional measures which will be described in Chapter 3. For example, implementation of a package of additional measures (Measure R) would lead to a further saving of 2.0 to 3.8million life years, additional to the 6.4 to 12.2 million life years from the baseline of measures already agreed. This is discussed further in section 3.4 of Chapter 3.

[90] It will be noted that this result does not exactly match the difference between the overall impact of 2005 levels of anthropogenic $PM_{2.5}$ minus the overall impact of 2020 levels of anthropogenic $PM_{2.5}$ in the earlier Table 2.13. This is probably mainly due to uncertainties in the $PM_{2.5}$ modelling, which are discussed further in Chapter 5.

KEY UPDATES TO THE CHAPTER

This chapter has been updated to reflect changes to the assumptions for existing measures, to include new measures that have been modelled in light of recent developments and better information received following the AQS review consultation period. This chapter provides complete evidence base of all measures assessed for the recent AQS review consultation and the new measures that have been modelled for the AQS.

The key changes to this chapter result from the change in the assumed rate of formation of sulphates and nitrates, as discussed in Chapter 2, section 2.4 of this report. The change in this assumption has been reflected in the new estimates of changes in concentrations and through revised damage cost estimates. This new assumption is applied to both analysis of new measures and updates to analysis of measures previously presented in the Third IGCB report.

The following new measures have been modelled and included alongside the measures presented in the previous version of this report:

- **Measure A2 (Euro revised)** has been modelled to reflect more recent European Parliament proposals for the new vehicle standards. While this better reflects our expectations of the new standards this new measure should continue to be considered alongside the additional scenario set out in Measure B (Euro high) due to current uncertainty as to the final outcome of negotiations. This measure is separate to the existing Measure A (Euro low) presented in the Third IGCB report analysis
- **Measure C2 (Early Euro revised)** has been modelled to show the early uptake scenario of Measure A2 above. This measure is separate to the existing Measure C (Early Euro low) presented in the Third IGCB report analysis
- **Combined measure R (Early Euro revised + LEV + Shipping)** has been modelled to reflect the package of measures identified by the new Air Quality Strategy to be considered. This includes the new measure on the early uptake of Euro Standards (based on Measure A2), the incentivisation of low emission vehicles and a measure aimed at reducing emissions from shipping.

The following individual measures have also been updated following recent developments and better information:

- In each of the transport measures where a change in fuel usage has been identified analysis has been revised to reflect more recent updates for the resource costs of fuel
- A box has been inserted under **Measure F (Road pricing)** setting out the key messages from the Eddington Transport Study and the Draft Transport Bill
- Analysis of **Measure G (LEZ)** has been supplemented with a box setting out the latest analysis from Transport for London on a London scheme[1]

KEY UPDATES TO THE CHAPTER *(continued)*

- The cost assumptions for **Measure H (Retrofit)** and its sub-measures have been revised as a result of new information received during the consultation process. Specifically this includes the removal of a fuel penalty (±1%) caused by the retrofit of diesel particulate filters (DPFs) and lower unit resource costs for the DPF technology. This has reduced the annualised costs for these measures although in most cases they continue to outweigh the annualised benefits at the 6% hazard rate reduction

- The costs and benefits of **Measure K1 (early LCP)** have been refined in light of the publication of the national plan for implementing the Large Combustion Plant Directive (LCPD) and to account for updated capital cost estimates for fitting SCR from industry

- Further discussion has been provided on the assumptions used for **Measure N (Shipping)** in light of consultation responses and can be found in section 3.3 below

All the chronic mortality results and net present values (NPVs) presented in this chapter have now been updated to bring them into line with the recent COMEAP recommendations discussed in section 2.5.3 of Chapter 2. As a result only the analysis using the 6% hazard rate reduction is presented in this chapter as this now represents the 'central estimate' in COMEAP's expert view.[2] Sensitivities around this 6% hazard rate reduction are discussed in sections 5.3. and 5.6 of Chapter 5.

[1] Available from www.tfl.gov.uk

[2] Department of Health (2007) Committee on the Medical Effects of Air Pollutants 'Long-term Exposure to Air Pollution: Effect on Mortality' Draft report for technical comment. http://www.advisorybodies.doh.gov.uk/comeap/statementsreports/longtermeffectsmort2007.pdf

3.1 Introduction

1. This chapter also presents the costs and benefits of new Measure R, which comprises the package of measures identified to be considered in the new Air Quality Strategy accompanying this report. This builds on the work completed for the AQS review, published in April 2006, and new measures modelled following its consultation (as set out in the box above). This chapter also presents the costs and benefits of new Measure R, which comprises the package of measures being proposed by the new Air Quality Strategy accompanying this report. A full description of the measures, the data and assumptions used in their appraisal, as well as the appraisal results will be presented in detail. Annex 6 at the end of this report also presents results at a devolved administration level.

2. The costs and benefits of the measures discussed in this chapter are incremental to the baseline scenario presented in Chapter 2, section 2.4 of this report. The baseline scenario, or counterfactual, consists of the current measures and future measures already agreed, that have been deployed to help meet the air quality objectives set out in the 2000 Air Quality Strategy. This includes measures agreed and set by the European Union, such as Euro IV standards for Light Duty Vehicles, and the Large Combustion Plant Directive as well as agreed national and local initiatives.

3. The general methodology used to carry out the cost-benefit analysis for the additional measures has been described in detail in Chapter 2, hence this chapter will only refer to methodological points that are specific to each measure.

3.2 Costs and benefits of road transport measures

4. This section presents the potential transport measures modelled for consideration for the Air Quality Strategy. It considers only the monetary estimates of the impacts of the transport measures, the non-monetised impacts are described in Chapter 4. The baseline assumptions for the emission projections of the transport measures are presented in Chapter 2, section 2.4 of this report. Box 3.1 explains the different definitions of the Euro standards that many of the transport measures are based on.

Box 3.1 Definition of Euro standards for light and heavy duty vehicles

Euro standards are sets of emission requirements that define maximum acceptable limits for emissions of new vehicles bought within the EU. Euro standards for light duty vehicles (passenger cars and light goods vehicles) are referenced by Arabic numerals (Euro 5, 6 etc.), where as for heavy duty vehicles (heavy goods vehicles, buses and coaches), the relevant standards are referenced with Roman numerals (Euro V, VI etc.). These conventions are incorporated into this report to create greater clarity in the terminology.

Although vehicle emissions standards have existed in the EU since the early 1970s, stringent Euro 1/I standards came into force, for both LDVs and HDVs, in 1993. These have been regularly tightened through successive Euro standards which set more stringent emission limits for the four main pollutants covered by Euro standards: oxides of nitrogen, carbon monoxide, hydrocarbons and, for diesel vehicles, particulate matter. Different emissions limits have existed for petrol and diesel vehicles since Euro 2 reflecting the fact that diesels are generally lower emitters of carbon monoxide and hydrocarbons, and petrol vehicles lower emitters of oxides of nitrogen and particulate matter.

In this report, the relevant standards are Euro 5 and 6 (for light duty vehicles) and Euro V and VI (for heavy duty vehicles) and the assumptions regarding these are explained in the related measures below.

5. The transport measures presented in this chapter include:

- Three versions of the European Regulations on Light Duty and Heavy Duty Vehicles (based on Euro standards 5/6 and V/VI), expected to be introduced in 2010. The three versions considered are a less intensive emission reductions scenario (existing Measure A), a version that reflects more recent proposals for the new standard (new Measure A2) and a more intensive emissions reduction scenario (Measure B);

- Two further variants of the Euro standard regulation are considered relating to increase early take up of the Euro standards. The two versions modelled relate to the less intensive Euro standards (Measure A) and the more recent proposals (Measure A2);
- Measure D, which considers incentives to phase out the most polluting vehicles (Euro I and pre Euro) from the car fleet;
- Measure E, which looks to increase the penetration of Low Emission Vehicles in the car fleet;
- Measure F, which considers the impacts associated with the introduction of a possible national road pricing scheme;
- Measure G, which considers the costs and the benefits of a theoretical London low emission zone (LEZ) and its theoretical extension to a further 7 large urban areas[1]; and
- Measure H, which considers the costs and benefits associated with an incentive mechanism encouraging retrofitting Diesel Particulate Filter (DPF) technology to heavy goods vehicles, buses and coaches that are already in the fleet but are not meeting Euro V standards.

Box 3.2: Definitions of transport cost terminology

The reader needs to be familiar with the definitions contained in this box as they will be encountered repeatedly when reading through the costs of the various transport measures:

- ***Technology costs:*** The technology costs for the transport measures are based on current knowledge and do not include reduced costs due to innovations in technology, which may occur in the future. The figures are quoted in 2005 prices. The technology costs are estimated assuming mass production (and constant returns to scale at mass production). Further sensitivity analysis on the costs of transport measures can be obtained in Chapter 5 of this report;

- ***Annualising technology costs:*** The majority of the costs of the transport measures A, A2, B, C, C2, E and H occur up-front (e.g. fitting certain technology to the vehicle during production increases the production costs of the vehicle) while the benefits occur over the lifetime of the vehicle (e.g. emission reductions occurs every year for every km driven by the vehicle). The technology costs and the operating costs are annualised based on the number of years the vehicles survive in the fleet so that the annual equivalent technology costs can be compared to the annual benefits. Annualising the costs finds the annual amounts, which are equivalent, in present value terms, to paying the capital cost up front. This method allows the comparison of costs with annual benefits, even if the measure is being looked at over a period which does not include the full lifetime of the vehicle;

[1] Note that the London Mayor confirmed on 9th May 2007 a scheme order for an actual London LEZ. The actual London scheme is substantially different from the phase 2 feasibility study on which Measures G1-G3 are based. It has not been possible to update these measures to reflect this new information.

Box 3.2: Definitions of transport cost terminology *(continued)*

- ***Fuel economy:*** This presents the number of kilometres travelled per litre of fuel consumed by the vehicle. Some of these measures, by virtue of different technology used, change the fuel economies of vehicles. If there is a positive impact on fuel economy, the vehicles have greater mileage per litre of fuel compared to the situation without the new technology; a negative impact on fuel economy implies the reverse. Greater fuel economy gives an incentive to drive a vehicle more and vice versa. This can lead to positive/negative impacts on the vehicle user. This is explained below;

- ***Rebound effect:*** The rebound effect captures the fact that when the fuel economy of vehicles increases, other things equal, the marginal cost of driving falls. This causes demand for travel in the more fuel efficient vehicles to rise. For example, when the elasticity of the rebound effect is -0.2, and a measure causes an increase in fuel economy of 5%, the rebound effect will cause the resulting fuel saving and carbon saving to be 4% of the original total, rather than 5%, as drivers respond to a fall in the price of driving with an increase in demand for driving; and

- ***Welfare effects due to the rebound effect:*** The cost models presented below take account of some of the welfare effect of the rebound effect. A fall in fuel economy means that for given expenditure, drivers use their cars less. This means that there is a welfare loss to society. Correspondingly, the extra mileage possible due to an increase in fuel economy will result in welfare gain. These effects are measured by estimating the change in the consumer surplus of individuals from the change in the marginal cost of driving a km, and the change in total km driven.

3.2.1 Measure A: Euro standards 5 and VI (low intensity scenario)

6. Measure A considers the costs and benefits of the implementation of the European Regulations of Euro 5 for diesel Light Duty Vehicles (including cars and vans) and Euro VI for diesel Heavy Duty Vehicles (including articulated and rigid heavy goods vehicles as well as buses and coaches).

7. The dates of implementation of these standards are assumed to be 2010 for LDVs and 2013 for HDVs after which these standards will be mandatory for all new vehicles. This measure only applies to new vehicles which enter the fleet on or after the dates mentioned.

8. The reductions proposed are over and above the reductions from the existing Euro 4 standards for LDVs and the Euro V standards for HDVs. The existing standards are included in the baseline scenario. The costs and benefits presented in this section are incremental over the baseline scenario.

   - 20% reduction in NO_X from all new diesel LDVs;
   - 90% reduction in PM from all new diesel LDVs; and
   - 50% reduction in NO_X from all new diesel HDVs.

9. As this measure is in the form of a European regulation it is assumed to apply uniformly across the UK and across the EU.

Benefits of Measure A

10. The reduction in emissions for this measure were estimated by Netcen[2] by considering the difference in emissions when penetrating the existing fleet with the Euro 5/VI vehicles with the emission reductions shown above. This measure assumes the fitting of Exhaust Gas Recirculation (EGR) technology to Euro 4 LDVs, and improved Selective Catalytic Reduction (SCR) systems to HDVs to deliver the above emission reductions. Introducing these new Euro standards are assumed not to change the rate at which the vehicle fleet renews itself, this is assumed to remain the same as the baseline.

11. This measure has a negative impact on fuel economies in all the vehicle types considered. A negative impact on fuel economy implies that the particular vehicle will use more fuel per km than a comparable Euro 4/V (i.e. a fuel penalty). This negative impact on fuel economies causes less vehicle kilometres to be driven as described in Box 3.1. Fuel economy assumptions for the different vehicle types in this measure are presented in the Table 3.1 below.

Table 3.1: Fuel economy assumptions by vehicle type for Measure A

Vehicle Type	Impact on fuel economy for vehicles entering the fleet in 2010 – 2014
Diesel Car	– 2%
Diesel LGV	– 2%
Articulated HGV	– 6%
Rigid HGV	– 6%

12. The negative impact on fuel economies is likely to result in less vehicle kilometres being driven, due to the rebound effects as described in Box 3.1, which would have a further knock-on effect on NO_X and PM emissions reducing those emission further. This rebound effect has not been modelled by Netcen.

13. Emissions from all relevant vehicle types have been taken from the National Atmospheric Emissions Inventory (NAEI) and the relevant forecast of future changes in emissions derived.

14. Detailed concentration mapping of the NO_X and PM_{10} emissions, resulting secondary particulate matter concentrations and resulting ozone concentrations was carried out in order to calculate the benefits of this measure (the methodology for the mapping has been described in more detail in Chapter 2). The change in concentrations from implementing Measure A is shown in Table 3.2 below.

[2] Stedman et al (2006) 'Projections of Air Quality in the UK for Additional Measures Scenarios for the 2005 Review of the Air Quality Strategy', National Atmospheric Emissions Inventory, AEA Technology, National Environmental Technology Centre. Report AEAT/ENV/R/1986.

Table 3.2: Change in concentrations by implementing Measure A for the UK disaggregated by country[a]

Country	Pollutant	Concentration changes relative to the baseline ($\mu g.m^{-3}$)[b]		
		2010	**2015**	**2020**
England	PM_{10}	(0.059)	(0.383)	(0.619)
	NO_2	(0.051)	(0.633)	(1.262)
	Ozone	0.004 – 0.0041	0.047 – 0.478	0.084 – 0.897
Northern Ireland	PM_{10}	(0.024)	(0.159)	(0.258)
	NO_2	(0.034)	(0.352)	(0.656)
	Ozone	0.002 – 0.009	0.010 – 0.088	0.020 – 0.109
Scotland	PM_{10}	(0.040)	(0.250)	(0.401)
	NO_2	(0.042)	(0.507)	(0.987)
	Ozone	0.001 – 0.017	0.021 – 0.195	0.021 – 0.300
Wales	PM_{10}	(0.031)	(0.210)	(0.363)
	NO_2	(0.036)	(0.499)	(1.006)
	Ozone	0.002 – 0.025	0.036 – 0.277	0.039 – 0.455
UK	PM_{10}	(0.055)	(0.358)	(0.578)
	NO_2	(0.049)	(0.607)	(1.209)
	Ozone	0.003 – 0.037	0.043 – 0.433	0.073 – 0.802

[a] Data presented in the table in brackets represents a negative impact

[b] Ozone concentration changes shown as a range incorporating results assuming both a zero threshold and a 50ppb threshold. PM_{10} concentrations are presented in ($\mu g.m^{-3}$, gravimetric).

15. The quantified health and non-health benefits have been calculated from the resulting concentrations using the methodology described in Chapter 2. Measure A will have a long term impact as it is assumed all future vehicles will emit less NO_X and PM_{10}. Hence, the benefit analysis is calculated on the assumption of a 100 year sustained pollution reduction. Table 3.3 illustrates the health impacts generated by the above changes in concentrations.

16. As Measure A is assumed to be a long term measure the 2020 concentrations are assumed to persist from 2010 to 2109 and the benefits are calculated on that basis. This is a simplification since detailed concentrations modelling undertaken for the AQS review show that, in general, the concentration changes build up from 2010 to 2020.

17. A more accurate representation would therefore be to take account of the sequential changes in PM concentrations: apply the 2010 concentration change between 2010-2014, the 2015 concentration change between 2015 and 2019 and the 2020 concentration change from 2020 onwards. Thus the simplified method described above leads to an overestimate in the calculation of benefits of this measure. Further analysis on the sensitivity of the benefits calculation to this assumption is presented in Chapter 5 of this report.

18. Due to the negative impact on fuel economy caused by the fuel penalties described above there are negative carbon impacts as a result of the technology. This is also shown in Table 3.3 below

Table 3.3: Quantified impacts of implementing Measure A[a]

PM life years saved ('000s) – 6% (2010 – 2109)	PM – RHA (2020 p.a.)	PM – CHA (2020 p.a.)	Ozone mortality (2020 p.a.)	Ozone RHA (2020 p.a.)	Carbon ('000s tonnes p.a.) (2020)
1,225 – 2,338	203	203	(277) – (25)	(320) – (29)	(500)

[a] Data presented in the table in brackets represents a negative impact – for ozone impacts this reflects the increase in population weighted ozone concentrations presented in the previous table.

19. These impacts have then been monetised using the methodology described in Chapter 2 and discounted to generate a Present Value (PV), in 2005 prices, of the different impacts. This present value has then been annualised. The monetary values can be seen in Table 3.4 below. These monetised impacts include the impacts on crop yields and damage to buildings and materials avoided due to the reduction in concentrations.

Table 3.4: Annual present value of impacts of implementing Measure A (£millions)[a]

PM life years saved – 6%	PM – RHA	PM – CHA	Ozone Mortality	Ozone RHA	Carbon	Crops	Buildings & materials
518 – 1,219	1 – 3	1 – 3	(4) – (0.12)	(5) – (0.09)	(46)	2	2

[a] Numbers in brackets represent negative values.

Costs of Measure A

20. The costs of this measure are driven primarily by the resource costs of the incremental technologies (beyond Euro 4/V) that have to be implemented to achieve the required emission reductions. The other costs of this measure include the impacts of the changes in fuel economies of vehicles compared to Euro 4/V vehicles, which include the changes in resource costs of fuel, as well as the welfare impacts of changes in the vehicle kilometres travelled due to changes in fuel efficiency.

- *Technology costs:* The unit costs of technology per vehicle type required to achieve the concentration reductions shown in Table 3.2 above are shown in Table 3.5 below. It is assumed that these technologies are fitted to new Euro 4 LDVs and Euro V HDVs at the time of manufacture to make them compliant with the Euro 5/VI regulation. The costs presented in Table 3.5 are the resource costs per unit which the producers have to face when manufacturing these equipments. The HGV technology costs are presented as a range reflecting the uncertainly in the estimates of resource costs of the equipment.

Table 3.5: Resource costs per unit of technology for Measure A (2005 prices)

Vehicle Type	Type of Technology	Costs per vehicle entering the fleet
Diesel Cars	Exhaust Gas Recirculation (EGR)	£178
Diesel LGVs	Exhaust Gas Recirculation (EGR)	£288
Articulated HGVs	Selective Catalytic Reducers	£1,000 – £1,500
Rigid HGVs	Selective Catalytic Reducers	£430 – £800

- *Resource cost of fuel:* Due to the fact that the introduction of these technologies in Euro 4/V vehicles will have a negative impact on the vehicle's fuel economy, the Euro 5/VI compliant vehicles will use more fuel per km compared the Euro 4/V vehicles that they replace. This difference in fuel consumed per km is based on the fuel penalties of the particular Euro standard and vehicle type. The fuel penalties for the technologies in this measure are shown in Table 3.1 above. This measure will thus have an effect on total fuel consumption. Additional fuel consumption is valued at the resource cost of fuel (i.e. no tax is included).
- *Welfare impacts of the negative impacts on fuel economy:* This measure also estimates the welfare impacts due to the negative impact on fuel economies and the resulting loss in the vehicle kilometres travelled.

21. The costs of this measure was estimated by a model designed for this measure by Department for Transport (DfT). The methodology for estimating the costs of this measure can be divided into two sections:

- *Methodology of estimating costs before 2020:* The technology costs presented in Table 3.5 above are annualised according to the methodology described in Box 3.1. The welfare costs due to the reduction in vehicle kilometres travelled (compared to the baseline) is estimated using the methodology described in Box 3.1. The increased resource costs of fuel due to the negative impacts on fuel economy of this measure is calculated by multiplying the difference in fuel consumed by the vehicles in this measure compared to the baseline with the latest DTI fuel price forecasts.

- *Methodology of estimating costs after 2020:* In order to maintain comparability between the cost and benefit estimation, the impacts (e.g. litres of fuel used, vehicle kms travelled) and the annualised technology costs of the measure in 2020 are assumed to apply each year from 2020 onwards to 2109. The costs beyond 2020 are extrapolated from the 2020 costs, assuming that impacts remain constant but applying the relevant fuel prices and social cost of carbon[3] for each year.

22. The costs for each vehicle type have been calculated according to the methodology described above and the total costs have been estimated by summing across all vehicle types. The total costs of the implementation of this measure in the UK are presented in Table 3.6 below. The total costs include the annualised technology costs, the resource costs of the measure as well as the welfare impacts due to the rebound effect. The costs are discounted using the standard appropriate Treasury Green Book[4] discount rate and annualised over the period between the implementation date for each vehicle type and 2109.

Table 3.6: Costs of implementing Measure A in the UK in 2005 prices (£millions)

Annualised Technology Costs	Annualised Resource cost of extra fuel consumed	Annualised Welfare impact due to rebound effect	Annual PV of Costs
262 – 268	119 – 120	1	382 – 389

Cost and benefits of Measure A

23. Table 3.7 below presents the annual Net Present Value (NPV) of Measure A, that is the annual benefits minus the annual costs. This is based on a 6% hazard rate reduction, for chronic mortality effects, and a range in possible lag times (0 or 40 years lag), as explained in Chapter 2.

Table 3.7: Annual costs and benefits of implementing Measure A in the UK (£millions)[a]

Annual PV of Costs	Annual PV of Benefits	Annual NPV
382 – 389	469 – 1,183	80 – 801

[a] Numbers in brackets represent negative values.

24. The table above shows that the benefits outweigh the costs of Measure A based on the recommended 6% hazard rate reduction for both the lag and the no-lag scenario.

[3] It is worth noting that the Stern review suggested that the cost of carbon used in government evaluations was significantly undervalued. The report suggested increasing the value to $85 per tonne of CO_2 (approx £160 per tonne of carbon). However as this figure has not been agreed across government therefore existing agreed value has been used.

[4] 'The Green Book: Appraisal and Evaluation in Central Government' HM Treasury (2003).

3.2.2. Measure A2: Euro standards 5/6/VI (revised scenario)

25. Measure A2 is new measure modelled to reflect later European Parliament proposals for the new vehicle standards. It requires a higher percentage reduction in NO_X but identical reductions in PM as set out in Measure A above. This version of the Euro standards applies to both diesel and petrol LDVs and to diesel HDVs.

26. The percentage reduction in NO_X and PM proposed by this measure is shown below:

- 28% reduction in NO_X from all new diesel LDVs in 2010;
- 72% reduction in NO_X from all new diesel LDVs in 2015;
- 13% reduction in NO_X from all new petrol LDVs by 2010;
- 90% reduction in PM from all new diesel LDVs in 2010; and
- 50% reduction in NO_X from all new diesel HDVs.

27. The dates of implementation of these standards are assumed to be 2010 (Euro 5) and 2015 (Euro 6) for LDVs and 2013 for HDVs (Euro VI) after which these standards will be mandatory for all new vehicles. This measure only applies to new vehicles which enter the fleet on or after the dates mentioned.

28. As this measure is in the form of a European regulation it is assumed to apply uniformly across the UK and across the EU.

Benefits of Measure A2

29. Similar to Measure A the reduction in emissions for this measure were estimated by Netcen[5] by considering the difference in emissions from the baseline when penetrating the existing fleet with the Euro 5/6/VI vehicles under this newly modelled revised scenario.

30. This measure has a negative impact on fuel economies in all the vehicle types considered. A negative impact on fuel economy implies that the particular vehicle will use more fuel per km than a comparable Euro 4/V (i.e. a fuel penalty). This negative impact on fuel economies causes less vehicle kilometres to be driven as described in Box 3.1. Fuel economy assumptions for the different vehicle types in this measure are presented in the Table 3.8 below.

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[5] Stedman et al (2006) 'Projections of Air Quality in the UK for Additional Measures Scenarios for the 2005 Review of the Air Quality Strategy', National Atmospheric Emissions Inventory, AEA Technology, National Environmental Technology Centre. Report AEAT/ENV/R/1986.

Table 3.8: Fuel economy assumptions by vehicle type for Measure A2

Vehicle Type	Impact on fuel economy for vehicles entering the fleet in 2010 – 2014	Impact on fuel economy for vehicles entering the fleet in 2015
Diesel Car	– 2%	– 3%
Petrol Car	0%	0%
Diesel LGV	– 2%	– 3%
Petrol LGV	0%	0%
Articulated HGV	– 6%	– 6%
Rigid HGV	– 6%	– 6%

31. The negative impact on fuel economies is likely to result in less vehicle kilometres being driven, due to the rebound effects as described in Box 3.1, which would have a further knock-on effect on NO_X and PM emissions reducing those emissions further. This rebound effect has not been modelled by Netcen.

32. Emissions from all relevant vehicle types have been taken from the National Atmospheric Emissions Inventory (NAEI) and the relevant forecast of future changes in emissions derived.

33. Detailed concentration mapping of the NO_X and PM_{10} emissions, secondary particulate matter concentrations and resulting ozone concentrations was carried out in order to calculate the benefits of this measure. The change in concentrations from implementing Measure A2 is shown in Table 3.9 below.

Table 3.9: Change in concentrations by implementing Measure A2 for the UK disaggregated by country[a]

Country	Pollutant	Concentration changes relative to the baseline ($\mu g.m^{-3}$)[b]		
		2010	**2015**	**2020**
England	PM_{10}	(0.029)	(0.436)	(0.668)
	NO_2	(0.072)	(0.908)	(1.925)
	Ozone	(0.001) – 0.029	0.017 – 0.467	0.040 – 1.005
Northern Ireland	PM_{10}	(0.014)	(0.160)	(0.280)
	NO_2	(0.050)	(0.536)	(0.924)
	Ozone	(0.004) – 0.002	(0.024) – 0.059	(0.097) – 0.050

Table 3.9: Change in concentrations by implementing Measure A2 for the UK disaggregated by country[a] *(continued)*

Country	Pollutant	Concentration changes relative to the baseline ($\mu g.m^{-3}$)[b]		
Scotland	PM_{10}	(0.018)	(0.243)	(0.420)
	NO_2	(0.058)	(0.751)	(1.525)
	Ozone	(0.004) – 0.011	(0.005) – 0.202	(0.035) – 0.334
Wales	PM_{10}	(0.017)	(0.227)	(0.404)
	NO_2	(0.051)	(0.864)	(1.387)
	Ozone	(0.006) – 0.014	(0.008) – 0.274	(0.049) – 0.506
UK	PM_{10}	(0.027)	(0.355)	(0.622)
	NO_2	(0.069)	(0.876)	(1.844)
	Ozone	(0.002) – 0.030	0.015 – 0.499	0.032 – 1.059

[a] Numbers in brackets represent negative values.

[b] Ozone concentration changes shown as a range incorporating results assuming both a zero threshold and a 50ppb threshold. PM_{10} concentrations are presented in ($\mu g.m^{-3}$, gravimetric).

34. The quantified health and non-health benefits have been calculated from the resulting concentrations using the methodology described in Chapter 2.

35. Measure A2 will have a long term impact as it is assumed that all future vehicles will emit less NO_X and PM_{10}. Hence, the benefit analysis is calculated on the assumption of a 100 year sustained pollution reduction. As Measure A2 is assumed to be a long term measure the 2020 concentrations are assumed to persist from 2010 to 2109 and the benefits are calculated on that basis. As explained in the benefits section of Measure A estimating benefits by this simplified method leads to a overestimation of benefits.

36. Due to the negative impact on fuel economy caused by the fuel penalties described above there are negative carbon impacts as a result of the technology. This is also shown in Table 3.10 below

Table 3.10: Quantified impacts of implementing Measure A2[a]

PM life years saved ('000s) – 6% (2010 – 2109)	PM – RHA (2020 p.a.)	PM – CHA (2020 p.a.)	Ozone mortality (2020 p.a.)	Ozone RHA (2020 p.a.)	Carbon ('000s tonnes p.a.) (2020)
1319 - 2518	219	219	(366) – (11)	(423) – (13)	(564)

[a] Data presented in the table in brackets represents a negative impact – for ozone impacts this reflects the increase in population weighted ozone concentrations presented in the previous table.

37. These benefits have then been monetised using the methodology described in Chapter 2 and discounted to generate a Present Value (PV), in 2005 prices, of the different impacts. This present value has then been annualised. The monetary values can be seen in Table 3.11 below. These monetised impacts include the impacts on crop yields and damage to buildings and materials avoided due to the reduction in concentrations.

Table 3.11: Annual present value of impacts of implementing Measure A2 (£millions)[a]

PM life years saved – 6%	PM – RHA	PM – CHA	Ozone Mortality	Ozone RHA	Carbon	Crops	Buildings & materials
584 – 1366	1 – 4	1 – 4	(5) – (0.05)	(5) – (0.05)	(51)	2	2

[a] Numbers in brackets represent negative values.

Costs of Measure A2

38. The costs of this measure are driven primarily by the resource costs of the incremental technologies (beyond Euro 4/V) that have to be implemented to achieve the required emission reductions. The other costs of this measure include the impacts of the changes in fuel economies of vehicles compared to Euro 4/V vehicles, which include the changes in resource costs of fuel, as well as the welfare impacts of changes in the vehicle kilometres travelled due to changes in fuel efficiency.

- *Technology costs:* The unit costs of technology per vehicle type required to achieve the concentration reductions shown in Table 3.9 above are shown in Table 3.12 below. It is assumed that these technologies are fitted to new Euro 4 LDVs and Euro V HDVs at the time of manufacture to make them compliant with the Euro 5/6/VI regulation. The costs presented in Table 3.12 are the resource costs per unit which the producers have to face when manufacturing these equipments. The HGV technology costs are presented as a range reflecting the uncertainly in the estimates of resource costs of the equipment.

Table 3.12: Resource costs per unit of technology for Measure A2 (2005 prices)

Vehicle Type	Type of Technology	Costs per vehicle entering the fleet between (2010 – 2014)	Costs per vehicle entering the fleet after 2015
Diesel cars	Diesel Particulate Filters and Selective Catalytic Reduction or Lean NO_X Traps	£196	£605
Petrol cars	Variable Valve Timing enabling Internal EGR	£12	£12

Table 3.12: Resource costs per unit of technology for Measure A2 (2005 prices) *(continued)*

Vehicle Type	Type of Technology	Costs per vehicle entering the fleet between (2010 – 2014)	Costs per vehicle entering the fleet after 2015
Diesel LGVs	Diesel Particulate Filters and Selective Catalytic Reduction or Lean NO_X Traps	£304	£1,089
Petrol LGVs	Variable Valve Timing enabling Internal EGR	£12	£12
Articulated HGVs	Selective Catalytic Reducers	£1,000 – £1,500	£1,000 – £1,500
Rigid HGVs	Selective Catalytic Reducers	£430 – £830	£430 – £830
Note: For LDVs SCR or LNT is assumed for 2015 onwards only.			

- *Resource cost of fuel:* Due to the fact that the introduction of these technologies will have an impact on their fuel economy, the Euro 5/6/VI compliant vehicles will use more or less fuel than the Euro 4/V vehicles based on the fuel penalties of the particular Euro 5/6/VI vehicle type. The change in resource costs of the fuel are valued using the latest DTI fuel projections.
- *Welfare impacts of the changes in fuel economies:* This measure also attempts to estimate the welfare impacts due to the changes in fuel economies and the resulting loss/gain in the vehicle kilometres travelled. Further explanation of welfare effects is given in Box 3.1.

39. In order to maintain comparability between the cost and benefit estimation, the impacts (increased technology costs, change in fuel used and rebound kilometres travelled) of the measure in 2020 are assumed to apply each year from 2020 onwards to 2109. The costs (technology costs, welfare costs and resource costs of fuel) accrued before 2020 are estimated according to the cost methodology described for Measure A.

40. The costs for each vehicle type have been calculated according to the methodology described above and the total costs of the measure have been estimated by summing across all vehicle types. The total costs of the implementation of this measure in the UK are presented in Table 3.13 below. The total costs include the annualised technology costs, the resource costs of the measure as well as the welfare impacts due to the rebound effect. The costs are discounted using the appropriate standard Green Book discount rate and annualised over the period between the implementation date for each vehicle type and 2109.

Table 3.13: Costs of implementing Measure A2 in the UK in 2005 prices (£millions)

Annualised Technology Costs	Annualised Resource cost of extra fuel consumed	Annualised Welfare impact due to rebound effect	Annual PV of Costs
648 – 652	139 – 140	1	788 – 793

Cost and benefits of Measure A2

41. Table 3.14 below presents the annual Net Present Value (NPV) of Measure A2, that is the annual benefits minus the annual costs. This is based on a 6% hazard rate reduction, for chronic mortality effects, and a range in possible lag times (0 or 40 years lag), as explained in Chapter 2.

Table 3.14: Annual costs and benefits of implementing Measure A2 in the UK (£millions)[a]

Annual PV of Costs	Annual PV of Benefits	Annual NPV
788 – 793	529 – 1,327	(264) - 539

[a] Numbers in brackets represent negative values.

42. The results in Table 3.14 above indicate that the costs outweigh the benefits of Measure A2 when the 6% hazard rate is used for the 40 year lag scenario. However for the no-lag scenario, the benefits significantly outweigh the costs. The latest statements from COMEAP suggest that, although evidence was limited,the Committee's judgement tends towards a greater proportion of the effect occurring in the years sooner after the pollution reduction rather than later. This would mean that the effect is more likely to be nearer the no lag result.

3.2.3 Measure B: Euro standards 5/6/VI (high reductions scenario)

43. Measure B considers a stricter version of the Euro standards 5/6/VI (compared to Measures A and A2) requiring a higher percentage reductions in NO_X and PM from vehicles. This version of the Euro standards applies to both diesel and petrol LDVs and to diesel HDVs.

44. The percentage reduction in NO_X and PM proposed by this measure are shown below:

- 50% reduction in NO_X from new petrol LDVs by 2010;
- 40% reduction in NO_X from new diesel LDVs in 2010;
- 68% reduction in NO_X from all new diesel LDVs in 2015;
- 75% reduction in NO_X for new HDVs; and
- 90% reduction in PM for all new diesel vehicles (HDVs and LDVs).

45. The initial reduction in NO_X for LDVs is assumed to apply from 2010 (Euro 5), the tighter NO_x for diesel LDVs from 2015 (Euro 6). The measure is assumed to be introduced in 2013 for HDVs (Euro VI). As this measure is in the form of a European regulation it is assumed to apply uniformly across UK and across Europe.

Benefits of Measure B

46. Similar to Measure A the reduction in emissions for this measure were estimated by Netcen[6] by considering the difference in emission from the baseline when penetrating the existing fleet with the Euro 5/6/VI vehicles.

47. Measure B also assumes the use of technologies which affect the fuel economies of vehicles compared to an equivalent new Euro 4/V vehicle. There will be changes in carbon emission based on these changes in fuel economies of vehicles. The negative impact on fuel economies causes less vehicle kilometres to be driven as described in Box 3.1. The impact on the fuel economies for the different vehicle types of this measure is presented in the Table 3.15 below.

Table 3.15: Fuel economy assumptions by vehicle type for Measure B

Vehicle Type	Impact on fuel economy for vehicles entering the fleet in 2010 – 2014	Impact on fuel economy for vehicles entering the fleet in 2015
Diesel Car	– 5%	– 5%
Petrol Car	0%	0%
Diesel LGV	– 5%	– 5%
Petrol LGV	0%	0%
Articulated HGV	– 9%	– 9%
Rigid HGV	– 9%	– 9%

48. Similar to Measure A, the air quality benefits do not include the rebound effects on vehicle kilometres from the overall changes in fuel economies that this measure causes.

49. Emissions from all relevant vehicle types have been taken from the National Atmospheric Emissions Inventory (NAEI) and the relevant forecast of future changes in emissions derived.

50. Detailed concentration mapping of the NO_X and PM_{10} emissions, resulting secondary particulate matter concentrations and resulting ozone concentrations was carried out in order to calculate the benefits of this measure (the methodology for the mapping has been described in more detail in Chapter 2 and the consultation document). The impact on concentrations due to this measure is presented in Table 3.16 below.

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[6] Stedman et al (2006) 'Projections of Air Quality in the UK for Additional Measures Scenarios for the 2006 Review of the Air Quality Strategy', National Atmospheric Emissions Inventory, AEA Technology, National Environmental Technology Centre. Report AEAT/ENV/R/1986.

Table 3.16: Change in concentrations by implementing Measure B for the UK disaggregated by country[a]

Country	Pollutant	Concentration changes relative to the baseline ($\mu g.m^{-3}$)[b]		
		2010	**2015**	**2020**
England	PM_{10}	(0.073)	(0.484)	(0.800)
	NO_2	(0.177)	(1.532)	(2.858)
	Ozone	0.013 – 0.125	0.107 – 1.096	0.156 – 1.888
Northern Ireland	PM_{10}	(0.030)	(0.200)	(0.331)
	NO_2	(0.113)	(0.895)	(1.413)
	Ozone	0.006 –0.033	0.018 – 0.194	0.106 – 0.133
Scotland	PM_{10}	(0.046)	(0.299)	(0.492)
	NO_2	(0.143)	(1.250)	(2.216)
	Ozone	0.005 – 0.057	0.048 – 0.438	0.006 – 0.550
Wales	PM_{10}	(0.042)	(0.293)	(0.488)
	NO_2	(0.129)	(1.259)	(2.228)
	Ozone	0.008 – 0.075	0.075 – 0.616	0.010 – 0.849
UK	PM_{10}	(0.068)	(0.450)	(0.746)
	NO_2	(0.170)	(1.476)	(2.731)
	Ozone	0.012 – 0.144	0.098 – 0.990	0.128 – 1.672

[a] Negative figures in brackets

[b] Ozone concentration changes shown as a range incorporating results assuming both a zero threshold and a 50ppb threshold. PM_{10} concentrations are presented in ($\mu g.m^{-3}$, gravimetric).

51. The quantified health and non-health benefits have been calculated from the resulting concentrations using the methodology described in Chapter 2.

52. Measure B will have a long term impact as it is assumed that all future vehicles will emit less NO_X and PM_{10}. Hence, the benefit analysis is calculated on the assumption of a 100 year sustained pollution reduction. As Measure B is assumed to be a long term measure the 2020 concentrations are assumed to persist from 2010 to 2109 and the benefits are calculated on that basis. As explained in the benefits section of Measure A estimating benefits this simplified method leads to an overestimating of benefits.

53. Table 3.17 illustrates the health impacts generated by the above changes in concentrations.

54. Due to the overall negative impact on the fuel economy by the fuel penalties described above there are negative carbon impacts due to the technology. This is also shown in Table 3.17 below.

Table 3.17: Quantified impacts of implementing Measure B[a]

PM life years saved ('000s) – 6% (2010 – 2109)	PM – RHA (2020 p.a.)	PM – CHA (2020 p.a.)	Ozone mortality (2020 p.a.)	Ozone RHA (2020 p.a.)	Carbon ('000s tonnes p.a.) (2020)
1,581 – 3,017	262	263	(579) – (44)	(668) – (51)	(939)

[a] Data presented in the table in brackets represents a negative impact – for ozone impacts this reflects the increase in population weighted ozone concentrations presented in the previous table.

55. These benefits have then been monetised using the methodology described in Chapter 2 and discounted to generate a Present Value (PV) in 2005 prices of the different impacts. This present value has then been annualised. The monetary values can be seen in Table 3.18 below. These monetised impacts include the impacts on crop yields and damage to buildings and materials avoided due to the reduction in concentrations.

Table 3.18: Annual present value of impacts of implementing Measure B (£millions)[a]

PM life years saved – 6%	PM – RHA	PM – CHA	Ozone Mortality	Ozone RHA	Carbon	Crops	Buildings & materials
669 – 1,571	1 – 4	1 – 4	(8) – (0.21)	(10) – (0.17)	(86)	2	2

[a] Numbers in brackets represent negative values.

Costs of Measure B

56. Similar to Measure A, the costs of this measure are driven primarily by the resource costs of the incremental technologies (beyond Euro 4/V) that have to be implemented to achieve the required emission reductions. Since the emission requirements are more stringent for this measure, the technology required is more expensive. The other costs of this measure include the impacts of the changes in fuel economies of vehicles compared to Euro 4/V vehicles, which include the changes in resource costs of fuel, as well as the welfare impacts of changes in the vehicle kilometres travelled due to changes in fuel economy.

- *Technology costs:* The unit costs of technology per vehicle type required to achieve the concentration reductions shown in Table 3.16 above are shown in Table 3.19 below. The costs presented in Table 3.19 below are the resource costs per unit which the producers have to incur when producing the equipments. It is assumed that these technologies are fitted to new Euro 4 LDVs and Euro V HDVs at the time of manufacture to make them compliant with the Euro 5/6/VI regulation. The HGV technology costs are presented as a range reflecting the uncertainly in the estimates of resource costs of the equipment.

Table 3.19: Resource costs per unit of technology for Measure B (2005 prices)

Vehicle Type	Type of Technology	Costs per vehicle entering the fleet between (2010 – 2014)	Costs per vehicle entering the fleet after 2015
Diesel cars	Diesel Particulate Filters + Selective Catalytic Reduction or Lean NO_x Traps	£230	£614
Petrol cars	Variable Valve Timing enabling Internal EGR	£50	£50
Diesel LGVs	Diesel Particulate Filters + Selective Catalytic Reduction or Lean NO_x Traps	£340	£1,106
Petrol LGVs	Variable Valve Timing enabling Internal EGR	£50	£50
Articulated HGVs	Diesel Particulate Filters + Selective Catalytic Reduction	£2,042 – £2,600	£2,042 – £2,600
Rigid HGVs	Diesel Particulate Filters + Selective Catalytic Reduction	£868 – £1,800	£868 – £1,800

Note: For LDVs SCR or LNT is assumed for 2015 onwards only.

- *Resource cost of fuel:* Due to the fact that the introduction of these technologies will have an impact on their fuel economy, the Euro 5/6/VI compliant vehicles will use more or less fuel than the Euro 4/V vehicles based on the fuel penalties of the particular Euro 5/6/VI vehicle type. The change in resource costs of the fuel are valued using the latest DTI fuel projections.
- *Welfare impacts of the changes in fuel economies:* This measure also attempts to estimate the welfare impacts due to the changes in fuel economies and the resulting loss/gain in the vehicle kilometres travelled. Further explanation of welfare effects are given in Box 3.1.

57. In order to maintain comparability between the cost and benefit estimation, the impacts (increased technology costs, change in fuel used and rebound kilometres travelled) of the measure in 2020 are assumed to apply each year from 2020 onwards to 2109. The costs (technology costs, welfare costs and resource costs of fuel) accrued before 2020 are estimated according to the cost methodology described for Measure A.

58. The costs for each vehicle type have been calculated according to the methodology described above and the total costs of the measure have been estimated by summing across all vehicle types. The total costs of the implementation of this measure in the UK are presented in Table 3.20 below. The total costs include the annualised technology costs, the resource costs of the measure as well as the welfare impacts due to the rebound effect. The costs are discounted using the standard Green Book discount rate and annualised over the period between the implementation date for each vehicle type and 2109.

Table 3.20: Costs of implementing Measure B in the UK in 2005 prices (£millions)

Annualised Technology Costs	Annualised Resource cost of extra fuel consumed	Annualised Welfare impact due to rebound effect	Annual PV of Costs
731 – 751	250	2	983 – 1,003

Cost and benefits of Measure B

59. Table 3.21 below presents the annual Net Present Value (NPV) of Measure B, which is the annual benefits minus the annual costs of Measure B. This is based on a 6% hazard rate reduction, for chronic mortality effects, and a range in possible lag times (0 or 40 years lag), as explained in Chapter 2.

Table 3.21: Annual costs and benefits of implementing Measure B in the UK (£millions)[a]

Annual PV of Costs	Annual PV of Benefits	Annual NPV
983 – 1,003	571 – 1,497	(432) – 514

[a] Numbers in brackets represent negative values.

60. The results in Table 3.21 above indicate that the costs outweigh the benefits of Measure B when the 6% hazard rate is used for the 40 year lag scenario. However for the no-lag scenario, the benefits significantly outweigh the costs. The latest statements from COMEAP suggest that, although evidence was limited, the Committee's judgement tends towards a greater proportion of the effect occurring in the years sooner after the pollution reduction rather than later. This would mean that the effect is more likely to be nearer the no lag result.

3.2.4 Measure C: Incentivising early uptake of Euro 5/V/VI standards (low scenario)

61. Measure C models a measure to encourage the Euro standards 5/V/VI for all diesel vehicles (both LDVs and HDVs) earlier than the proposed dates of implementation.

62. This measure is based on the low intensity version of the Euro standard (i.e. Measure A). New Euro standards for cars and goods vehicles are likely to become mandatory for new cars in 2010 and for new HGVs in 2013. However, vehicles which meet these standards could be available before the standards become mandatory. This measure is assumed to apply to new cars only, and will not apply for new vehicles purchased after the new standards become mandatory.[7]

63. The impacts of this measure revert back to Measure A after the new standards become mandatory. The benefits become very similar to Measure A by about 2020. This measure is assumed to apply uniformly across the UK.

64. The modelled early uptake rates within the vehicle fleet are set out in Table 3.22 below. These uptake rates were determined by what was thought to be technologically feasible and realistic given past experience. In addition to the early uptake of Euro VI by HGVs, there is a small amount of early uptake of Euro V by HGVs compared to the baseline scenario. This is also shown in the table below.

Table 3.22: Percentage early uptake in the fleet

Type of Vehicle	2007	2008	2009	2010	2011	2012	2013
Diesel cars (Euro 5)	25%	50%	75%	Euro 5 now mandatory			
Diesel LGVs (Euro 5)	25%	50%	75%	Euro 5 now mandatory			
Rigid HGVs (Euro V)	15%	23%	Euro V now mandatory				
Articulated HGVs (Euro V)	15%	23%	Euro V now mandatory				
Rigid HGVs (Euro VI)	0%	0%	0%	25%	50%	75%	Euro VI now mandatory
Articulated HGVs (Euro VI)	0%	0%	0%	25%	50%	75%	Euro VI now mandatory

[7] The cost of any scheme to increase uptake has note been included. If for example an incentive were provided this would not be included in any CBA as it is a transfer.

Benefits of Measure C

65. The benefits of Measure C were estimated by Netcen.[8] The benefits are similar to Measure A, the only difference being that they begin earlier. Measure C is assumed to revert back to Measure A, rather than the baseline scenario by 2020, therefore this Measure will have a long term health impact. The benefits of this Measure were modelled by adding the difference between the benefits of Measure A and Measure C over a 20 year period to the long term benefits of Measure C (estimated over a 100 period using the 2020 concentrations).

66. Table 3.23 below shows concentrations disaggregated by country due to the implementation of this measure.

Table 3.23: Change in concentrations by implementing Measure C for the UK disaggregated by country[a]

Country	Pollutant	Concentration changes relative to the baseline (μg.m-3)[b]		
		2010	2015	2020
England	PM_{10}	(0.152)	(0.349)	(0.654)
	NO_2	(0.191)	(0.847)	(1.347)
	Ozone	0.017 – 0.134	0.069 – 0.618	0.092 – 0.947
Northern Ireland	PM_{10}	(0.062)	(0.190)	(0.272)
	NO_2	(0.112)	(0.473)	(0.705)
	Ozone	0.006 – 0.041	0.015 – 0.131	0.019 – 0.123
Scotland	PM_{10}	(0.101)	(0.297)	(0.422)
	NO_2	(0.153)	(0.695)	(1.053)
	Ozone	0.007 – 0.067	0.034 – 0.269	0.026 –0.325
Wales	PM_{10}	(0.086)	(0.269)	(0.383)
	NO_2	(0.140)	(0.670)	(1.074)
	Ozone	0.010 –0.078	0.052 – 0.357	0.044 – 0.481
UK	PM_{10}	(0.142)	(0.428)	(0.609)
	NO_2	(0.183)	(0.814)	(1.290)
	Ozone	0.016 – 0.123	0.063 – 0.561	0.080 – 0.847

[a] Negative figures in brackets

[b] Ozone concentration changes shown as a range incorporating results assuming both a zero threshold and a 50ppb threshold. PM_{10} concentrations are presented in (μg.m^{-3}, gravimetric).

[8] Stedman et al (2006) 'Projections of Air Quality in the UK for Additional Measures Scenarios for the 2006 Review of the Air Quality Strategy', National Atmospheric Emissions Inventory, AEA Technology, National Environmental Technology Centre. Report AEAT/ENV/R/1986.

67. This measure has a negative impact on fuel economies in all the vehicle types considered. A negative impact on fuel economy implies that the particular vehicle will use more fuel per km than a comparable Euro 4/IV (i.e. a fuel penalty). This negative impact on fuel economies causes less vehicle kilometres to be driven as described in Box 3.1. Fuel economy assumptions for the different vehicle types in this measure are presented in the Table 3.24 below.

Table 3.24: Fuel economy assumptions by vehicle type for Measure C

Vehicle Type	Impact on fuel economy for vehicles
Diesel Car	– 2%
Diesel LGV	– 2%
Articulated HGV (Euro V)	– 4%
Rigid HGV (Euro V)	– 4%
Articulated HGV (Euro VI)	– 6%
Rigid HGV (Euro VI)	– 6%

68. The negative impact on fuel economies is likely to result in less vehicle kilometres being driven, due to the rebound effects as described in Box 3.1, which would have a further knock-on effect on NO_X and PM emissions. reducing those emission further. This rebound effect has not been modelled by Netcen.

69. Table 3.25 presents the health impacts of Measure C. As noted above the carbon impacts from this measure are negative.

Table 3.25: Quantified impacts of implementing Measure C[a]

PM life years saved ('000s) – 6% (2010 – 2109)	PM – RHA (2020 p.a.)	PM – CHA (2020 p.a.)	Ozone mortality (2020 p.a.)	Ozone RHA (2020 p.a.)	Carbon ('000s tonnes p.a.) (2020)
1,366 – 2,543	214	214	(293) – (28)	(339) – (32)	(552)

[a] Data presented in the table in brackets represents a negative impact – for ozone impacts this reflects the increase in population weighted ozone concentrations presented in the previous table.

70. The monetised health impacts of Measure C are presented in Table 3.26 below. This table also includes the impacts on crops, buildings and materials.

Table 3.26: Annual present value of impacts of implementing Measure C (£millions)[a]

PM life years saved – 6%	PM – RHA	PM – CHA	Ozone Mortality	Ozone RHA	Carbon	Crops	Buildings & materials
618 – 1,396	1 – 3	1 – 3	(4) – (0.14)	(5) – (0.11)	(50)	2	2

[a] Numbers in brackets represent negative values.

Costs of Measure C

71. The costs of Measure C are similar to that of Measure A, the only difference being that they apply earlier due to the incentive effect. The costs of Measure C are modelled over the period 2006 (for LGVs) and 2010 (for HGVs) to 2029 and then added to the costs of Measure A.

72. The value of the any encouragement is not considered as part of the costs of the measure as it is not a resource cost. For example were a financial incentive used it would be a transfer payment between the person providing the incentive and the person receiving it.

73. As such, similar to Measure A, the costs of Measure C are:

- *Technology costs:* The resource costs of technology are included, annualised over the number of years the vehicles survive in the fleet. The technology costs per vehicle are similar to those of Measure A. However this measure also incorporates early uptake of Euro V in HGVs and therefore the technology costs of this measure also includes the technology costs of the Euro V HGVs.

Table 3.27: Resource costs per unit of technology for Measure C (2005 prices)

Vehicle Type	Type of Technology	Costs per vehicle entering the fleet
Diesel Cars	Exhaust Gas Recirculation (EGR)	£178
Diesel LGVs	Exhaust Gas Recirculation (EGR)	£288
Articulated HGVs (Euro V)	Selective Catalytic Reducers	£378
Rigid HGVs (Euro V)	Selective Catalytic Reducers	£275
Articulated HGVs (Euro VI)	Selective Catalytic Reducers	£1,000 – £1,500
Rigid HGVs (Euro VI)	Selective Catalytic Reducers	£430 – £800

- *The resource costs of fuel:* As shown in Table 3.24 the Euro 5/6/V/VI technologies for diesel vehicles have fuel penalties (i.e. the vehicles use more fuel per km compared to an equivalent Euro 4/IV/V vehicle). Thus this measure incorporates the resource costs of the extra fuel consumed.

- *Welfare impacts:* The costs also include the welfare costs of the reduction in vehicle kilometres travelled due to the rebound effect (for an explanation of the rebound effect please refer to Box 3.1)

74. The annualised cost of the measure categorised according to the costs listed above summed across all vehicle types affected in the fleet are presented in Table 3.28 below.

Table 3.28: Costs of implementing Measure C in the UK in 2005 prices (£millions)

Annualised Technology Costs	Annualised Resource cost of extra fuel consumed	Annualised Welfare impact due to rebound effect	Annual PV of Costs
276 – 284	132	1	409 – 417

Costs and benefits of Measure C

75. Table 3.29 below presents the annual Net Present Value (NPV) of Measure C, that is the annual benefits minus the annual costs of Measure C. This is based on a 6% hazard rate, for chronic mortality effects, and a range in possible lag times (0 or 40 years lag), as explained in Chapter 2.

Table 3.29: Annual costs and benefits of implementing Measure C in the UK (£millions)[a]

Annual PV of Costs	Annual PV of Benefits	Annual NPV
409 – 417	565 – 1,356	148 – 947

[a] Numbers in brackets represent negative values.

76. The table above shows that the benefits outweigh the costs of measure C based on the recommended 6% hazard rate reduction for both the 40-year lag and the no-lag scenario.

Measure C2: Incentivising early uptake of Euro 5/V/VI standards (revised scenario)

77. Measure C2 is a new measure modelling a measure to encourage the Euro standards 5/V/VI for all diesel vehicles (both LDVs and HDVs) earlier than the proposed dates of implementation, based on Measure A2 (Euro revised). This measure forms part of the proposed package of measures in the Air Quality Strategy and part of the new combined measure R. This Measure is assumed to apply to new cars only, and will not be given for new vehicles purchased after the new standards become mandatory.

78. New Euro standards for cars and goods vehicles are likely to become mandatory for new cars in 2010 and for new HGVs in 2013. However, vehicles which meet these standards could be available before they become mandatory. This measure is assumed

to apply to new cars only, and will not apply for new vehicles purchased after the new standards become mandatory.[9]

79. The impacts of this measure revert back to Measure A2 after the new standards become mandatory. The benefits become very similar to Measure A2 by about 2020. This measure is assumed to apply uniformly across the UK.

80. The modelled early uptake rates within the vehicle fleet are set out in Table 3.30 below. These uptake rates were determined by what was thought to be technologically feasible and realistic given past experience and based on the latest implementation timetable for Euro 5/V/VI standards. In addition to the early uptake of Euro VI by HGVs, there is a small amount of early uptake of Euro V by HGVs compared to the baseline scenario. This is also shown in the table below.

Table 3.30: Percentage early uptake in the fleet

Type of Vehicle	2007	2008	2009	2010	2011	2012	2013
Diesel cars (Euro 5)	0%	33%	66%	Euro 5 now mandatory			
Diesel LGVs (Euro 5)	0%	33%	75%	Euro 5 now mandatory			
Rigid HGVs (Euro V)	15%	48%	Euro V now mandatory				
Articulated HGVs (Euro V)	15%	48%	Euro V now mandatory				
Rigid HGVs (Euro VI)	0%	0%	0%	25%	50%	75%	Euro VI now mandatory
Articulated HGVs (Euro VI)	0%	0%	0%	25%	50%	75%	Euro VI now mandatory

Benefits of Measure C2

81. The benefits of Measure C2 were estimated by Netcen. The benefits are similar to Measure A2, the only difference being that they begin earlier. Measure C2 is assumed to revert back to Measure A2, rather than the baseline scenario by 2020, therefore this Measure will have a long term health impact. The benefits of this Measure were modelled by adding the difference between the benefits of Measure A2 and Measure

[9] However, since the incentive is a transfer payment, this has not been included in the cost benefit analysis (some deadweight loss may be involved, but this has not been valued).

C2 over a 20 year period to the long term benefits of Measure C2 (estimated over a 100 period using the 2020 concentrations).

82. Table 3.31 below shows concentrations disaggregated by country due to the implementation of this measure.

Table 3.31: Change in concentrations by implementing Measure C2 for the UK

Country	Pollutant	Concentration changes relative to the baseline ($\mu g.m^{-3}$)[a]		
		2010	2015	2020
England	PM_{10}	(0.102)	(0.436)	(0.668)
	NO_2	(0.242)	(1.204)	(2.056)
	Ozone	0.004 – 0.121	0.030 – 0.648	0.041 – 1.071
Northern Ireland	PM_{10}	(0.044)	(0.190)	(0.294)
	NO_2	(0.147)	(0.683)	(0.973)
	Ozone	(0.004) – 0.024	(0.026) – 0.090	(0.109) – 0.044
Scotland	PM_{10}	(0.065)	(0.284)	(0.440)
	NO_2	(0.198)	(0.988)	(1.621)
	Ozone	(0.004) – 0.058	0.001 – 0.281	(0.041) – 0.348
Wales	PM_{10}	(0.061)	(0.272)	(0.424)
	NO_2	(0.184)	(0.999)	(1.660)
	Ozone	(0.006) – 0.070	(0.001) – 0.387	(0.057) – 0.533
UK	PM_{10}	(0.095)	(0.420)	(0.653)
	NO_2	(0.233)	(1.161)	(1.968)
	Ozone	0.004 – 0.130	0.030 – 0.693	0.031 – 1.128

[a] Ozone concentration changes shown as a range incorporating results assuming both a zero threshold and a 50ppb threshold. PM_{10} concentrations are presented in ($\mu g.m^{-3}$, gravimetric).

83. This measure has a negative impact on fuel economies in all the vehicle types considered. A negative impact on fuel economy implies that the particular vehicle will use more fuel per km than a comparable Euro 4/V (i.e. a fuel penalty). This negative impact on fuel economies causes less vehicle kilometres to be driven as described in Box 3.1. Fuel economy assumptions for the different vehicle types in this measure are presented in the Table 3.32 below.

Table 3.32: Fuel economy assumptions by vehicle type for Measure C2

Vehicle Type	Impact on fuel economy for vehicles entering the fleet in 2010 – 2014	Impact on fuel economy for vehicles entering the fleet in 2015
Diesel Car	– 2%	– 3%
Petrol Car	0%	0%
Diesel LGV	– 2%	– 3%
Petrol LGV	0%	0%
Articulated HGV	– 6%	– 6%
Rigid HGV	– 6%	– 6%

84. The negative impact on fuel economies is likely to result in less vehicle kilometres being driven, due to the rebound effects as described in Box 3.1, which would have a further knock-on effect on NO_X and PM emissions, reducing emissions further. This rebound effect has not, however, been modelled by Netcen.

85. Table 3.33 presents the health impacts of Measure C2. As noted above this measure results in increased carbon emissions.

Table 3.33: Quantified impacts of implementing Measure C2[a]

PM life years saved ('000s) – 6% (2010 – 2109)	PM – RHA (2020 p.a.)	PM – CHA (2020 p.a.)	Ozone mortality (2020 p.a.)	Ozone RHA (2020 p.a.)	Carbon ('000s tonnes p.a.) (2020)
1,445 – 2,701	230	230	(390) – (11)	(451) – (12)	(616)

a Data presented in the table in brackets represents a negative impact – for ozone impacts this reflects the increase in population weighted ozone concentrations presented in the previous table.

86. The monetised health impacts of Measure C2 are presented in Table 3.34 below. This table also includes the impacts on crops, buildings and materials.

Table 3.34: Annual present value of impacts of implementing Measure C2 (£millions)[a]

PM life years saved – 6%	PM – RHA	PM – CHA	Ozone Mortality	Ozone RHA	Carbon	Crops	Buildings & materials
637 – 1,454	1 – 4	1 – 4	(5) – (0.05)	(6) – (0.05)	(55)	2	2

[a] Numbers in brackets represent negative values.

Costs of Measure C2

87. The costs of Measure C2 are similar to that of Measure A2, the only difference being that they apply earlier due to the incentive effect. The costs of Measure C2 are modelled over the period 2006 (for LGVs) and 2010 (for HGVs) to 2029 and then added to the costs of Measure A2.

88. The value of the any encouragement is not considered as part of the costs of the measure as it is not a resource cost. For example were a financial incentive used it would be a transfer payment between the person providing the incentive and the person receiving it.

89. As such, similar to Measure A2, the costs of Measure C2 are:

- *Technology costs:* The resource costs of technology are included, annualised over the number of years the vehicles survive in the fleet. The technology costs per vehicle are similar to those of Measure A2. However this measure also incorporates early uptake of Euro V in HGVs and therefore the technology costs of this measure also includes the technology costs of the Euro V HGVs.

Table 3.35: Resource costs per unit of technology for Measure C2 (2005 prices)

Vehicle Type	Type of Technology	Costs per vehicle entering the fleet between (2010 – 2014)	Costs per vehicle entering the fleet after 2015
Diesel cars	Diesel Particulate Filters + Selective Catalytic Reduction or Lean NO_X Traps	£196	£605
Petrol cars	Variable Valve Timing enabling Internal EGR	£12	£12
Diesel LGVs	Diesel Particulate Filters + Selective Catalytic Reduction or Lean NOX Traps	£304	£1,089
Petrol LGVs	Variable Valve Timing enabling Internal EGR	£12	£12
Articulated HGVs	Selective Catalytic Reducers	£1,000 – £1,500	£1,000 – £1,500
Rigid HGVs	Selective Catalytic Reducers	£430 – £830	£430 – £830
Note: For LDVs SCR or LNT is assumed for 2015 onwards only.			

- *The resource costs of fuel:* As shown in Table 3.32 the Euro 5/V/VI technologies for diesel vehicles have fuel penalties (i.e. the vehicles use more fuel per km compared to an equivalent Euro 4/IV vehicle). Thus this measure incorporates the resource costs of the extra fuel consumed.

- *Welfare impacts:* The costs also include the welfare costs of the reduction in vehicle kilometres travelled due to the rebound effect (for an explanation of the rebound effect please refer to Box 3.1)

90. The annualised cost of the measure categorised according to the costs listed above summed across all vehicle types affected in the fleet are presented in Table 3.36 below.

Table 3.36: Costs of implementing Measure C2 in the UK in 2005 prices (£millions)

Annualised Technology Costs	Annualised Resource cost of extra fuel consumed	Annualised Welfare impact due to rebound effect	Annual PV of Costs
671 – 677	144 – 145	1	816 – 823

Costs and benefits of Measure C2

91. Table 3.37 below presents the annual Net Present Value (NPV) of Measure C2, that is the annual benefits minus the annual costs of Measure C2. This is based on a 6% hazard rate reduction, for chronic mortality effects, and a range in possible lag times (0 or 40 years lag), as explained in Chapter 2.

Table 3.37: Annual costs and benefits of implementing Measure C2 in the UK (£millions)[a]

Annual PV of Costs	Annual PV of Benefits	Annual NPV
816 – 823	577 – 1,411	(246) – 595

[a] Numbers in brackets represent negative values.

92. The table above shows that the costs outweigh the benefits of Measure C2 when the 6% hazard rate is used for the 40 year lag scenario. However for the no-lag scenario, the benefits significantly outweigh the costs. The latest statements from COMEAP suggest that, although evidence was limited, the Committee's judgement tends towards a greater proportion of the effect occurring in the years sooner after the pollution reduction rather than later. This would mean that the effect is more likely to be nearer the no lag result.

3.2.5 Measure D: Programme of incentives to phase out the most polluting vehicles (e.g. pre-Euro)

93. Measure D assumes a programme of incentives to phase out the most polluting vehicles from the existing car fleet. This measure is assumed to come into effect from 2007. This measure only affects emissions and concentrations over a short timeframe and is appraised according to two measures:

- **Measure D1:** This measure models the costs and benefits of incentivising scrappage of all pre-Euro I cars.

- **Measure D2:** This measure is more ambitious, it models the costs and benefits of incentivising the scrappage of all pre-Euro I and Euro I cars.

94. The modelled uptake rates of the incentive are set out in Table 3.38 below. These uptake rates were determined by what was thought to be feasible and realistic. This measure is assumed to apply uniformly across the UK.

Table 3.38: Percentage uptake of incentive in fleet

Measure	2007	2008	2009
Uptake of incentive to scrap pre-Euro cars	25%	50%	100%
Uptake of incentive to scrap pre-Euro and Euro I cars	25%	50%	100%

Benefits of Measure D1

95. Netcen's fleet projections suggest that pre-Euro I cars make up 1.9% of the petrol car fleet and 0.6% of the diesel car fleet in 2007, decreasing to 0.54% and 0.14% by 2009, respectively, in the normal turnover in the fleet. This equates to a population of 387,000 pre-Euro I petrol cars and 38,100 pre-Euro I diesel cars in 2007.

96. It is possible that many of these cars would have left the fleet naturally due to the turnover in the fleet. The modelling results suggest that Measure D1 reduces emissions by only a small amount. The maximum saving in road transport emissions of NO_X achieved in 2008 compared to baseline projections is about 1%.

97. Thus taking into account the small reductions in emissions, this measure was only modelled in terms of emissions and not using concentrations modelling. The impact on emissions is presented in Table 3.39 below.

Table 3.39: Change in emissions by implementing Measure D1 for the UK

Country	Pollutant	Emissions Saved (tonnes)		
		2010	2015	2020
UK	PM_{10}	12	0	0
	NO_X	818	0	0

98. The damage cost methodology described in Chapter 2 provides not only monetary estimates of the benefits of reductions in a tonne of pollutant but also the associated health impacts. Therefore, in order to calculate the physical impact of the above reductions in emissions, the NO_X and PM_{10} emissions changes in 2010 were multiplied by the per tonne health impacts over the period 2010 to 2014.

99. Table 3.40 illustrates the health impacts generated by the emission reductions of Measure D1. This measure also has a positive impact on carbon emissions, due to the replacement of less fuel efficient cars by more fuel efficient ones in the fleet. However, around 15-30% of carbon emissions from cars are due to the production and scrappage stage, rather than the use stage.[10] Thus shortening the lives of cars entails additional carbon emissions. This negative 'knock-on' impact on carbon has not been estimated for this analysis due to lack of accurate information on the size of this impact.

Table 3.40: Quantified impacts of implementing Measure D1[a]

PM life years saved ('000s) – 6% (2010 – 2014)	PM – RHA (2010 p.a.)	PM – CHA (2010 p.a.)	Carbon ('000s tonnes p.a.) (2010)
0.3	5	5	3

[a] Data presented in the table in brackets represents a negative impact – for ozone impacts this reflects the increase in population weighted ozone concentrations presented in the previous table.

100. The benefits were estimated by applying the per tonne damage costs to the change in 2010 emissions over the period 2010 to 2014. The monetary values can be seen in Table 3.41 below.

Table 3.41: Annual present value of impacts of implementing Measure D1 (£millions)[a]

PM life years saved – 6%	PM – RHA	PM – CHA	Carbon
0.94 – 1.36	0 – 0.001	0 – 0.001	0.36

[a] Numbers in brackets represent negative values.

Benefits of Measure D2

101. The scheme becomes more effective when Euro I cars are included. This is primarily because there is a larger proportion of the fleet which is now under the influence of this measure and thus helps deliver higher benefits. This is represented in Table 3.42 below which shows the fleet projections of Netcen and shows the percentage of the fleet which will be impacted by the scheme in 2007 and 2010.

Table 3.42: Fleet projection and the proportion of Euro I cars for Measure D2

Vehicle type	% total fleet in 2007	% of total fleet in 2010	Number in fleet in 2007	Number in fleet in 2010
Euro I Petrol	11.7%	3.1%	2,330,000	582,000
Euro I Diesel	8.7%	1.7%	568,000	147,000

[10] See Teufel et al (1996) and Elghali et al (2004).

102. The results show that Measure D2 reduces emissions by a greater amount than measure D1: around 4% is the maximum saving in road transport emissions of NO_X, achieved in 2008 compared with the baseline measure. Thus for this measure detailed concentrations modelling has been undertaken. The changes in concentrations for this measure are presented in Table 3.43 below.

Table 3.43: Change in concentrations by implementing Measure D2 for the UK disaggregated by country

Country	Pollutant	Concentration changes relative to baseline ($\mu g.m^{-3}$)[a]		
		2010	2015	2020
England	PM_{10}	(0.021)	(0.012)	0.000
	NO_2	(0.168)	(0.005)	0.000
Northern Ireland	PM_{10}	(0.010)	(0.005)	0.000
	NO_2	(0.130)	(0.003)	0.000
Scotland	PM_{10}	(0.013)	(0.006)	0.000
	NO_2	(0.137)	(0.004)	0.000
Wales	PM_{10}	(0.014)	(0.009)	0.000
	NO_2	(0.126)	(0.004)	0.000
UK	PM_{10}	(0.021)	(0.011)	0.000
	NO_2	(0.162)	(0.004)	0.000

[a] Ozone concentration changes shown as a range incorporating results assuming both a zero threshold and a 50ppb threshold. PM_{10} concentrations are presented in ($\mu g.m^{-3}$, gravimetric).

103. Table 3.44 presents the health impacts of Measure D2. The health benefits have been estimated over a 10 year period, based on a sequential lifetable i.e. the lifetable took account of the modelled changes in population-weighted concentrations in both 2010 and 2015. The modelled difference in population- weighted concentrations between the measure and the baseline in 2010 was assumed to apply in the lifetable between 2010 and 2014; the modelled difference in population-weighted concentrations in 2015 was assumed to apply in the lifetable between 2015 and 2019. From 2020, the modelling showed no further impacts from this measure. The lifetable impacts were followed up until 2109 and the corresponding decrease in years of life lost calculated accordingly. The concept and impact of using a sequential life table is discussed in more detail in section 5.3.3.17 of Chapter 5. All acute mortality and morbidity effects were also assessed over 10 years, taking account of the changes in population-weighted concentrations in both 2010 and 2015. Similar to Measure D1 above the carbon impacts from this measure are positive as this scheme removes fuel inefficient vehicles from the fleet to be replaced by more fuel efficient ones.

Table 3.44: Quantified impacts of implementing Measure D2[a]

PM life years saved ('000s) – 6% (2010 – 2014)	PM – RHA (2010 p.a.)	PM – CHA (2010 p.a.)	Carbon ('000s tonnes p.a.) (2010)
7	6	6	64

[a] Data presented in the table in brackets represents a negative impact – for ozone impacts this reflects the increase in population weighted ozone concentrations presented in the previous table.

104. The monetised health impacts are presented in Table 3.45 below. This table also includes the impacts on buildings.

Table 3.45: Annual present value of impacts of implementing Measure D2 (£millions)[a]

PM life years saved – 6%	PM – RHA	PM – CHA	Carbon
11 – 15	0.001 – 0.002	0.001 – 0.002	0.11

[a] Numbers in brackets represent negative values.

Costs of Measure D

105. The key driver of the costs of Measure D is the fact that useful resources (cars) are being destroyed. This cost is estimated by calculating the market value of the cars in the year that they are scrapped. It is an estimate of the value of the service that the car would have provided for the rest of its lifetime, had it not been scrapped. The lost capital value of the cars is estimated for both the measures over the period of the measure.

106. The incentive applied to this measure is not included as a cost of the measure due to the fact that it is a transfer payment between the person who is giving the incentive and the person receiving it.

107. Another impact of this scheme is the reduction in theft that can arise due to the implementation of this scheme. Newer cars have a lower risk of theft than older cars. The value of the car itself is not included as this is normally just a transfer between the owner and the thief. The reduction in cost per theft assumes that total car crime is reduced as a result of a newer fleet, rather than simply being displaced. Thus this avoided cost is likely to be a maximum value and may be an overestimate of the impacts of the measure.

108. This model assumes that the cars which are scrapped are replaced by a new Euro IV car, thus obviously, Euro IV cars will be more fuel efficient than the scrapped pre-Euro or Euro I cars. As a result this scheme will have a resource cost saving for fuel.

109. This model however is unable to take into account a number of other impacts of the scheme. Noise impacts are discussed qualitatively in Chapter 4, section 4.6 of this report. In addition, there may be improvements in safety from the introduction of

newer vehicles in the fleet but also administrative costs from running the scheme. Wider economic impacts such as distortions that may arise in the car markets due to this measure have not been estimated.

110. Cash for scrappage schemes increase the demand for second hand cars. This is likely to increase the price of second hand cars. The scrapping incentive effectively puts a lower bound on the market value of old vehicles eligible for the scheme. They will not be sold in the used car market for an amount of money below the bonus. If the scheme is large enough, there may be a shortage in the local supply of this vehicle. This may mean that either there are imports of older dirtier vehicles from abroad, or lower income households will have to put off their purchase of an old car for more years. The costs model assumes that the market is not distorted, and that older dirtier vehicles are not imported from abroad. Relaxing this assumption could greatly increase the net cost of the scheme, but we do not believe this alternative outcome is very likely.

111. The costs are discounted using the appropriate standard Green Book discount rate and annualised over the period between the 2007 – 2013 for Measure D1 and 2007 – 2016 for Measure D2. The total costs of Measures D1 and D2 are shown in Table 3.46 below.

Table 3.46: Costs of implementing Measure D in the UK in 2005 prices (£millions)

Measure	Annualised lost capital value of cars	Annualised resource cost of reduced fuel consumed	Annualised reductions in theft	Annual PV of Costs
D1	6	(1)	(0.27)	5
D2	125	(12)	(1)	112

Costs and benefits of Measure D

112. Table 3.47 below presents the annual Net Present Value (NPV) of Measure D, that is the annual benefits minus the annual costs of Measure D. This is based on a 6% hazard rate reduction, for chronic mortality effects, and a range in possible lag times (0 or 40 years lag), as explained in Chapter 2.

Table 3.47: Annual costs and benefits of implementing Measure D in the UK (£millions)[a]

	Annual PV of Costs	Annual PV of Benefits	Annual NPV
D1	5	1 – 2	(4) – (3)
D2	112	15 – 19	(97) – (93)
[a] Numbers in brackets represent negative values.			

113. The results in Table 3.47 above indicate that the costs outweigh the benefits of Measure D for both sub-measures, even though not all the costs have been monetised.

3.2.6 Measure E: Increased uptake of low emission vehicles (LEVs)

114. This measure presents the costs and benefits of pursuing a scheme to increase penetration of diesel and petrol low emission vehicles (LEVs) into the fleet. This measure is assumed to apply to new cars only and is to apply from 2006 uniformly across UK. This measure forms part of the proposed package of measures in the Air Quality Strategy and part of the new combined measure R.

115. In the context of this measure, low emissions vehicles are defined as any vehicles meeting emission standards better than those of Euro 4 for NO_X and PM_{10} and below the current industry voluntary agreement for carbon. The assumed percentage reduction in emissions compared to a standard Euro 4 car is shown in Table 3.48 below.

Table 3.48: Percentage reductions in emission compared to Euro 4 vehicles

LEV emission savings		NO_X	PM	CO_2
Diesel Low Emission Vehicles	All road types	80%	92%	29%
Petrol Low Emission Vehicles	All road types	38%	0%	34%

116. It is assumed that this measure is capable of achieving the uptake rates shown in Table 3.49 below. For the purpose of simplicity this measure assumed that individuals substitute petrol LEVs for petrol Euro 4s and diesel LEVs for diesel Euro 4s when they purchase new cars.

Table 3.49: Uptake rates of petrol and diesel LEVs for Measure E

LEV vehicle Type	% Uptake in fleet in 2006	% Uptake in fleet in 2010	% Uptake in fleet in 2015	% Uptake in fleet in 2020
Diesel Low Emission Vehicles	1%	5%	13%	20%
Petrol Low Emission Vehicles	2%	10%	18%	25%

Benefits of Measure E

117. The benefits of this measure were modelled using the percentage reductions in emissions and the uptake rates outlined in the tables above.

118. Detailed concentration mapping of the PM_{10} and NO_X emissions was carried out in order to calculate the benefits of this measure (the methodology for the mapping has been described in more detail in Chapter 2 and the consultation document).

119. Table 3.50 below shows concentrations disaggregated by country due to the implementation of this measure.

Table 3.50: Change in concentrations by implementing Measure E for the UK disaggregated by country

Country	Pollutant	Concentration changes relative to baseline ($\mu g.m^{-3}$)[a]		
		2010	2015	2020
England	PM_{10}	(0.008)	(0.032)	(0.042)
	NO_2	(0.029)	(0.112)	(0.233)
	Ozone	0.002 – 0.018	0.010 – 0.064	0.022 – 0.132
Northern Ireland	PM_{10}	(0.003)	(0.014)	(0.020)
	NO_2	(0.017)	(0.078)	(0.158)
	Ozone	0.001 – 0.006	0.005 – 0.019	0.005 – 0.039
Scotland	PM_{10}	(0.004)	(0.017)	(0.026)
	NO_2	(0.027)	(0.094)	(0.203)
	Ozone	0.001 – 0.009	0.006 – 0.034	0.012 – 0.067
Wales	PM_{10}	(0.005)	(0.021)	(0.025)
	NO_2	(0.022)	(0.087)	(0.213)
	Ozone	0.002 – 0.010	0.006 – 0.037	0.016 – 0.075
UK	PM_{10}	(0.007)	(0.029)	(0.039)
	NO_2	(0.028)	(0.108)	(0.228)
	Ozone	0.002 – 0.016	0.009 – 0.059	0.021 – 0.121

[a] Ozone concentration changes shown as a range incorporating results assuming both a zero threshold and a 50ppb threshold. PM_{10} concentrations are presented in ($\mu g.m^{-3}$, gravimetric).

120. The quantified health and non-health benefits have been calculated from the resulting concentrations using the methodology described in Chapter 2. Measure E will have a long term impact; hence, the benefit analysis is calculated on the assumption of a 100 year sustained pollution reduction. Table 3.51 illustrates the health impacts generated by the above changes in concentrations.

121. As Measure E is assumed to be a long term measure the 2020 concentrations are assumed to persist from 2010 to 2109 and the benefits are calculated on that basis.

122. Due to the large emission savings shown in Table 3.50, there are large reductions in carbon relative to the baseline. These improvements in fuel economy cause the cost of driving per km to fall resulting in more vehicle kilometres being driven, causing some incremental emissions of the pollutants. However this rebound effect on the air quality benefits has not been modelled.

Table 3.51: Quantified impacts of implementing Measure E[a]

PM life years saved ('000s) – 6% (2010 – 2109)	PM – RHA (2020 p.a.)	PM – CHA (2020 p.a.)	Ozone mortality (2020 p.a.)	Ozone RHA (2020 p.a.)	Carbon ('000s tonnes p.a.) (2020)
82 – 157	14	14	(42) – 7	(48) – (8)	994

[a] Data presented in the table in brackets represents a negative impact – for ozone impacts this reflects the increase in population weighted ozone concentrations presented in the previous table.

123. These benefits have then been monetised using the methodology described in Chapter 2 and discounted to generate a Present Value (PV) in 2005 prices of the different impacts. This present value has then been annualised. The monetary values can be seen in Table 3.52 below. These monetised impacts include the impacts on crop yields and damage to buildings and materials avoided due to the reduction in concentrations.

Table 3.52: Annual present value of impacts of implementing Measure E (£millions)[a]

PM life years saved – 6%	PM – RHA	PM – CHA	Ozone Mortality	Ozone RHA	Carbon	Crops	Buildings & materials
35 – 82	0.05 – 0.22	0.05 – 0.22	(1) – (0.03)	(1) – (0.03)	91	(0.20)	0.03

[a] Numbers in brackets represent negative values.

Costs of Measure E

124. Similar to the other transport measures the costs can be divided into the following categories:

- *Technology costs:* The resource costs of technology are included, annualised over the number of years the vehicles survive in the fleet. The costs have been estimated based on the difference between vehicles meeting the LEV emissions specified in the measure and 'equivalent' cars that have higher emissions. The cost methodology takes into account differences in the purchase costs as well as differences in the characteristics of the LEV and comparator vehicle. LEVs typically have smaller engines and are physically smaller than the comparator vehicles. This difference in quality has been monetised using a hedonic price model[11] and is added to the difference in retail costs. This incremental cost per low emission vehicle is presented in Table 3.53 below. Further sensitivity analyses of these costs are presented in Chapter 5 of this report.

[11] Adamson K. A. (2005) 'Calculating the Price Trajectory of Adoption of Fuel Cell Vehicles', International Journal of Hydrogen Energy, 30

Table 3.53: Unit costs of technology for Measure E

	Petrol	Diesel
Extra cost of LEV over comparable Euro 4 vehicle	£600	£1,200

- *Resource costs of fuel:* As shown in Table 3.48, the LEVs have high levels of fuel efficiencies. They use much less fuel per km compared to an equivalent Euro 4 vehicle. Thus this measure incorporates the reductions in resource costs of the reduced fuel consumed.
- *Welfare impacts:* Due to the fact that LEVs have significant fuel benefits compared to a normal Euro 4 vehicle, individuals are able to enjoy greater vehicle kilometres travelled per litre. Thus as opposed to other transport measures there are welfare benefits of the increase in vehicle kilometres travelled due to the rebound effect (for an explanation of the rebound effect please refer to Box 3.1)

125. In order to maintain comparability between the cost and benefit estimation, the impacts (increased technology costs, change in fuel used and rebound kilometres travelled) of the measure in 2020 are assumed to apply each year from 2020 onwards to 2109. However although the impacts remain constant every year from 2020 – 2109, their valuation depends on the resource cost of fuel (DTI fuel forecast), and the social cost of carbon for that year[12].

126. As the measure is implemented from 2006, the costs between 2006 – 2020 depend on the annual estimates of the change in vehicle kilometres travelled, litres of fuel consumed and annual equivalent technology costs for each vehicle type. Thus effectively the costs are ramped up from 2006 to 2020; from there on they remain broadly constant subject to the values per impact e.g. fuel costs per litre.

127. The costs are discounted using the appropriate standard Green Book discount rate and annualised over the period between the implementation date and 2109.

128. Although this analysis takes into account the quality costs that the individuals may face when substituting to a LEV from a standard Euro 4 vehicle, there may be other costs which individuals face when making the change. The cost methodology presented above does not take into account other costs[13] in terms of the resistance of drivers to switching to new technologies. There is a distinct possibility that incorporating both the costs associated with resistance to change as well as the quality costs in estimating the incremental costs of the low emission vehicle may lead to some 'double-counting' of the costs of the measure. Therefore only the quality costs have been presented in this chapter. Sensitivity analysis of the costs of this measure presented in Chapter 5 will consider the effect of both costs on the NPV this measure.

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[12] Stern review suggested that the cost of carbon used in government evaluations was significantly undervalued. The report suggested increasing the value to $85 per tonne of CO_2 (approx £160 per tonne of carbon). However as this figure has not been agreed across government the existing agreed value has been used.

[13] Lane, B. (2005) 'Car-buyer Research Report: Consumer Attitudes to Low-carbon and Fuel-efficient Passenger Cars', London: Low Carbon Vehicle Partnership, March 2005

129. The costs of the measure summed across all the vehicle types is presented in Table 3.54 below.

Table 3.54: Costs of implementing Measure E in the UK in 2005 prices (£millions)

Annualised Technology Costs	Annualised Resource cost of extra fuel consumed	Annualised Welfare impact due to rebound effect	Annual PV of Costs
295	(227)	(7)	61

130. From the table above it can be seen that due to the positive fuel efficiencies, and the positive welfare impacts, the resource costs and welfare costs are negative. These decrease the cost impact of the associated technology.

Costs and benefits of Measure E

131. Table 3.55 below presents the annual Net Present Value (NPV) of Measure E, that is the annual benefits minus the annual costs of Measure E. This is based on a 6% hazard rate reduction, for chronic mortality effects, and a range in possible lag times (0 or 40 years lag), as explained in Chapter 2 of this report.

Table 3.55: Annual costs and benefits of implementing Measure E in the UK (£millions)[a]

Annual PV of Costs	Annual PV of Benefits	Annual NPV
61	124 – 173	63 – 112

[a] Numbers in brackets represent negative values.

132. Table 3.55 shows that this measure generates a net benefit under both the lag and no lag scenarios. However as outlined previously in the cost section of this measure, the costs of this measure have significant uncertainties. Further analysis of the impact on the NPV of this measure when a sensitivity analysis is conducted on the costs is presented in Chapter 5, section 5.4 of this report.

3.2.7 Measure F: Road pricing scheme

133. This measure considers the introduction of a national road pricing scheme, using evidence from the road pricing feasibility study, and its supporting reports.[14] A national road pricing scheme could take a variety of different forms and this analysis considers only one possible variant for illustrative purposes only in order to give an indication of the potential impacts. No decisions have been taken on what form national road pricing would take, or how it might operate, if this measure were to be introduced. It is highly unlikely that any 'real world' scheme would reflect the scenario that has been used for this assessment. This measure is assumed to apply in Great Britain only.

[14] 'Feasibility Study of Road Pricing in the UK', Department for Transport (2004a). Available at http://www.dft.gov.uk/stellent/groups/dft_roads/documents/divisionhomepage/029798.hcsp

134. It should be noted that there is a particularly high degree of uncertainty surrounding the costs and benefits of this measure. This reflects the fact that it is unlikely to be feasible before about 2015, and the inherent uncertainties surrounding future technological developments and movements in technology-related costs.

135. Since this analysis was undertaken in the Third IGCB report significant further work has been completed on the feasibility of road pricing. The key messages of these pieces of work are outlined in Box 3.3.

Box 3.3: Recent Developments on Road Pricing

The two key developments on road pricing since the publication of the Air Quality Strategy review have been:

- The Eddington Transport Study[1]; and
- The Draft Transport Bill.

Sir Rod Eddington was jointly commissioned by the Chancellor of the Exchequer and the Secretary of State for Transport to examine the long-term links between transport and the UK's economic productivity, growth and stability, within the context of the Government's broader commitment to sustainable development. The Study reported on 1 December 2006 accompanying the 2006 Pre-Budget Report

A key conclusion was that 'road pricing stands out in its potential to deliver economic benefits'. This conclusion was based on analysis extending the work undertaken by the 2004 Road Pricing Feasibility Study, looking at the impact in 2025 taking account of both congestion and carbon impacts.

The results of this modelling were that a well targeted national road pricing scheme could reduce congestion by some 50 per cent in 2025 and reduce the economic case for additional strategic road infrastructure by 80 per cent. Thereby creating a benefit that could total £28 billion a year.

This analysis did not however monetise the value the associated air pollution impacts. Given the scale of these impacts it would also generate a substantial contribution to air quality.

A Draft Local Transport Bill was published by Government in 2007. As part of a wider package of measures to tackle congestion and improve public transport, the draft Bill proposes a series of reforms to the existing legislation to ensure that those local authorities who wish to develop local road pricing schemes have the freedom and flexibility to do so in a way that best meets local needs.

[1] Transport's role in sustaining the UK's productivity and competitiveness ' Department for Transport & HM Treasury (2006). Available from http://www.hm-treasury.gov.uk/independent_reviews/eddington_transport_study

Benefits of Measure F

136. The benefits of a national road pricing scheme were analysed using information from the modelling that was undertaken as part of the Road Pricing Feasibility study. This modelling is described in more detail in Annex B of the study.[15]

137. A number of different scenarios were modelled to forecast the impact of different pricing schemes on transport outcomes. These scenarios set charges, which differed between level of congestion, road type, and area type, based on marginal social costs. The marginal social costs are the additional costs that a vehicle may impose on society, over and above the costs that the individual or company has to bear, due to the vehicle's impact on problems such as congestion, accidents and emissions.

138. The scenario used for the estimation of the air quality benefits of this illustrative assessment assumed marginal social pricing, with a maximum of 10 charge bands, capped at 80 pence/km. The 2010 emissions data from this scenario was extrapolated for future years and used to model changes in population-weighted concentrations of pollutants. It should be noted that the air quality benefits of a national road pricing scheme make up only a small proportion of the overall benefits; benefits in terms of time saved due to reduced congestion would be much greater than the air quality benefits.

139. The measure is assumed to reduce emissions and population weighted concentrations in perpetuity; in order to estimate the benefits, the change in population-weighted concentration in 2020 is assumed to apply between 2010 and 2109.

140. The concentration changes in 2010, 2015 and 2020 as a result of the road pricing scheme is illustrated in Table 3.56 below.

[15] Available at http://www.dft.gov.uk/stellent/groups/dft_roads/documents/page/dft_roads_029735.pdf

Table 3.56: Change in concentrations by implementing Measure F for the UK disaggregated by country

Country	Pollutant	Concentration changes relative to baseline ($\mu g.m^{-3}$)[a]		
		2010	2015	2020
England	PM_{10}	0.000	(0.116)	(0.105)
	NO_2	0.000	(0.299)	(0.281)
Northern Ireland	PM_{10}	0.000	(0.014)	(0.010)
	NO_2	0.000	(0.051)	(0.048)
Scotland	PM_{10}	0.000	(0.052)	(0.046)
	NO_2	0.000	(0.207)	(0.194)
Wales	PM_{10}	0.000	(0.033)	(0.023)
	NO_2	0.000	(0.138)	(0.145)
UK	PM_{10}	0.000	(0.103)	(0.093)
	NO_2	0.000	(0.276)	(0.261)

[a] Ozone concentration changes shown as a range incorporating results assuming both a zero threshold and a 50ppb threshold. PM_{10} concentrations are presented in ($\mu g.m^{-3}$, gravimetric).

141. The physical impacts of Measure F are shown in Table 3.57 below. The estimate of carbon tonnes is taken from recent work undertaken for the Climate Change Programme Review.[16]

Table 3.57: Quantified impacts of implementing Measure F[a]

PM life years saved ('000s) – 6% (2010 – 2014)	PM – RHA (2010 p.a.)	PM – CHA (2010 p.a.)	Carbon ('000s tonnes p.a.) (2010)
196 – 374	33	33	1,500

[a] Data presented in the table in brackets represents a negative impact – for ozone impacts this reflects the increase in population weighted ozone concentrations presented in the previous table.

142. These benefits have then been monetised using the methodology described in Chapter 2 and discounted to generate a Present Value (PV) in 2005 prices of the different impacts. This present value has then been annualised. The monetary values for the air quality benefits can be seen in Table 3.58 below. These monetised impacts include damage to buildings avoided due to the reduction in concentrations.

[16] 'UK Climate Change Programme 2006', Defra (2006b). Available at http://www.defra.gov.uk/environment/climatechange/index.htm

Table 3.58: Annual present value of impacts of implementing Measure F (£millions)[a]

PM life years saved – 6%	PM – RHA	PM – CHA	Buildings & materials
83 – 195	0.11 – 1	0.11 – 1	0.13

[a] Numbers in brackets represent negative values.

Costs of Measure F

143. Costs for this measure were considered in the Cost Model report published as part of the DfT's Road User Charging Feasibility Implementation Workstream.[17]

144. The costs were for a scenario that assumed that there would be a national framework for road pricing and that on-board units would be mandatory.[18]

145. The work done for the feasibility study suggested that the costs for such a scheme would be substantial but are very uncertain.

146. Any estimates are unlikely to reflect actual costs of any scheme given the rapidly developing nature of technology in this areas, and the Government's strategy of developing road pricing in areas where congestion is a problem today, or soon will be, in order to pilot technology to open up the possibility of a national road pricing scheme in the longer term.

Costs and benefits of Measure F

147. In view of the degree of uncertainty surrounding the likely costs and benefits of this potential future measure, it is not possible to generate meaningful estimates of its net present value. In line with its manifesto commitment, the Government is undertaking further work to examine the potential for moving away from the current system of motoring taxation towards a system of national road pricing, which will help to inform future decisions on whether such a scheme would yield overall net benefits. No decisions have been taken on a national scheme. The Government is working with local authorities interested in exploring the scope for developing local schemes to tackle local congestion problems. We expect the first of these to be in place in 4-5 years. It is only the evidence we get from established schemes that any decision on national road pricing would be made.

3.2.8 Measure G: London and LEZs

148. This measure considers the costs and the benefits of a theoretical London low emission zone (LEZ) and a theoretical extension to the 7 largest urban areas outside London.

149. The London Mayor confirmed on 9th May 2007 a scheme order for an actual London LEZ. The actual London scheme is substantially different from the phase 2 feasibility study on which Measures G1-G3 are based. It has not been possible to update these measures to reflect this new information.

[17] Available at http://www.dft.gov.uk/stellent/groups/dft_roads/documents/page/dft_roads_029770.pdf

[18] Scenario 9 within the cost model report.

150. The measures considered are

- Measure G1: A theoretical London LEZ first phase (2007), which would introduce a Euro II + Reduced Pollution Certificate (RPC)[19] standard for all HGVs and coaches (all buses are assumed to comply under the mayoral strategy).[20]
- Measure G2: Phase 2 of the theoretical London LEZ, which would introduce a Euro III + RPC standard for all HGVs, coaches and buses in 2010. An alternative considering a NO_X based RPC (equivalent to Euro IV) is also being considered.[21]
- Measure G3: An equivalent scheme Euro II + RPC standard (equivalent to the London first phase) introduced in 2010 in 7 other major areas (this scenario assumes that an LEZ applies to the central areas of Glasgow, Manchester, Liverpool, Sheffield, Newcastle, Birmingham, and Leeds).[22]

151. Each of the three measures (G1–G3) is based on the London LEZ phase 2 feasibility study, The results are intended to provide an indicative view of the scale of benefits and costs and as an update to the estimates presented in the Third IGCB report. It must also be noted that the cost estimates presented in this section relate to market prices rather than resource costs.

152. On 2nd February 2007, TfL completed a 13-week consultation on detailed proposals for the London Low Emission Zone scheme now confirmed by the Mayor, in the form of a scheme order[23]. The consultation proposals are also different from the phase 2 feasibility study on which Measures G1-G3 are based. Unfortunately given the timing and the ongoing development of the scheme, it has not been possible to update these measures to fully reflect the latest information.

153. In this supporting analysis for the TfL consultation an approximation of the potential impact using the IGCB methodology has been presented[24]. However, as IGCB was not involved in the production of this analysis it is not possible to verify these results beyond noting that the approach used appears to be sound. It was also not possible to provide the range of non-monetary assessments present for the other Measures. Therefore the results of this modelling are not presented alongside the consideration of the other measures. The results are however summarised in Box 3.4 to provide comprehensive analysis.

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19 The RPC scheme enables vehicles with modifications or particulate traps fitted to reduce particulate matter to benefit from reduced VED.

20 The proposed scheme here is based on the London LEZ phase 2 feasibility study, available at http://www.tfl.gov.uk/tfl/low-emission-zone/pdfdocs/phase-2-feasibility-summary.pdf. The scheme to be taken forward is as announced by the Mayor in May 2007, and there are substantial differences between the actual and theoretical schemes.

21 The proposed scheme here is based on the London LEZ phase 2 feasibility study, available at http://www.tfl.gov.uk/tfl/low-emission-zone/pdfdocs/phase-2-feasibility-summary.pdf. Further work is progressing on the London LEZ which may affect the exact scheme taken forward.

22 A similar phase 2 (Euro III + RPC) for the other 7 areas, which would be introduced in 2013 was considered, but has not been assessed in detail.

23 http://www.tfl.gov.uk/tfl/low-emission-zone/consultation.asp

24 To note an approximation of the IGCB methodology was labelled the “Defra methodology” within this analysis.

Box 3.4: TfL updated analysis on the London Low Emission Zone

In assessing the latest available information for the London LEZ analysis was undertaken by a number of parties with AEA Technology assessing the health impacts, Steer Davis Gleave reviewing the economic and business impacts and TfL estimating their cost in operating the proposal. The combined results of these assessments are summarised below.

Estimated costs and benefits of the proposed LEZ[1]

(£million)	Cost to TfL	Cost to operators	IGCB Method	Benefits EU CAFE method
High	132	220	220	675
Low	130	150	155	250

These estimates show that both benefits and costs have increased substantially following the phase 2 feasibility study. While there are a number of key differences in both the methodology and proposals to which they are applied. This section cannot explore all the differences but provided below are the key differences:

- Dates of implementation and scope have been altered to address issues arising from responses to the previous consultation;
- The distinction between the different phases of implementation has been removed;
- Outside London benefits have been re-estimated; and
- There have been changes in the means of enforcing the London LEZ.

[1] The presented results differ slightly from the figures presented in the consultation as they incorporate analysis undertaken following the consultation. The key differences being that the benefits presented here relate to the 'whole life cost' modelling which is consistent with the presented cost estimates. The cost estimate to operators have also been revised to estimate resource costs of abatement equipment rather than market prices, to be consistent with the consideration of other measures in this report. However the costs to TfL and for the purchase of new vehicles have remain market costs and therefore the costs are overestimates.

Benefits of Measure G1

154. The benefits of the theoretical London LEZ first phase have been estimated, based on the emissions benefits predicted in the phase 2 feasibility study.[25] This includes the benefits in year 1, plus additional benefits in later years above the baseline; note that the benefits of the theoretical LEZ drop in each successive year over the baseline, due to the natural turnover of the fleet over time.

155. The benefits have been assessed over an 8 year period from 2007 to 2014, using the damage cost methodology described in Chapter 2 i.e. applying the relevant per tonne damage cost to the change in emissions each year between 2007 and 2014.

[25] Watkiss et al (2003) 'London Low Emission Zone Feasibility Study. Phase II. Final Report to the London Low Emission Zone Steering Group', AEA Technology Environment, July 2003.
Available at http://www.tfl.gov.uk/tfl/low-emission-zone/pdfdocs/phase-2-feasibility-summary.pdf.

156. The change in emissions in 2010, 2015 and 2020 are shown in Table 3.59 and the resultant quantified health impacts are shown in Table 3.60.

Table 3.59: Change in emissions by implementing Measure G1

Country	Pollutant	Emissions Saved (tonnes)		
		2010	2015	2020
UK	PM_{10}	59	0	0
	NO_x	241	0	0

Table 3.60: Quantified impacts of implementing Measure G1

PM life years saved ('000s) – 6% (2007 - 2014)	PM – RHA (2010 p.a.)	PM – CHA (2010 p.a.)
4	4	4

157. These benefits have been monetised using the damage cost methodology described in Chapter 2 discounted to generate a Present Value (PV) in 2005 prices.[26] The results are shown in Table 3.61 below.

Table 3.61: Annual present value of impacts of implementing Measure G1 (£millions)

PM life years saved ('000s) – 6%	PM – RHA	PM – CHA
8 – 12	0.01 – 0.03	0.01 – 0.04

158. The theoretical schemes should also lead to benefits outside London, from a cleaner fleet operating across the UK. Based on assessment of the theoretical measures, it is clear that a London LEZ would influence national emissions (as some 30% of all lorries enter London each year and some 50% of all coaches).There would therefore be benefits outside London from cleaner vehicles affected by the London LEZ travelling around the M25, on routes to London, and on other trips around the UK during the course of a year. These benefits have been estimated, based on recent work undertaken to progress the implementation of the actual London LEZ. These imply additional annualised benefits outside London of £0.6 to £5.2 million, using the AQS review damage costs. There are also additional benefits predicted from the LEZ, including noise benefits, due to the higher noise levels from pre-Euro and Euro I vehicles, which would be excluded with the scheme. These noise benefits have been estimated at £1 – £2 million in the first year of the scheme.

[26] The estimated air quality benefits in the first year of introduction from the LEZ, based upon the impacts in Table 3.46 using the current methodology, are £3 to £24 million. This compares to an estimate of first year benefits from the phase 2 feasibility study of £26 million. The benefits of an LEZ are very high in the first year of introduction, then fall in future years, relative to the improvements that would have occurred in the baseline.

Costs of Measure G1

159. The costs of this measure were obtained from the reports from AEA Technology and TTR.[27]

160. The potential costs of the theoretical LEZ were obtained by assessing the costs of implementing and operating the scheme, and also the costs to operators from enforced changes to comply with the zone.

161. The set-up and operational costs of the scheme depend on the enforcement method chosen. The phase 2 feasibility scheme for London considered both a manual and automatic scheme. These costs have been updated here, and it is estimated a scheme targeting heavy vehicles via manual enforcement would have start-up costs of £2.8 million and annual running costs of £4.2 million/year. If this scheme were implemented using automatic enforcement, then costs would rise to a start-up cost of £8.9 million and annual running costs of £4.0 million/year. The costs exclude the potential revenues from the scheme (as these are a transfer). Assuming an eight-year lifetime (consistent with benefits above), the costs are shown below.

Table 3.62: Possible annual present value of scheme costs for Measure G1 (£millions)

Annual PV of Scheme Costs
4 – 5

162. Therefore, based upon the costs presented above, the benefits of the theoretical London LEZ scheme exceed the costs of the scheme for the 3% and 6% risk rates (40 year and no lag).

163. However, the costs of the scheme also depend on the costs to operators, which depend on the response of the operators with non-compliant vehicles (effectively pre-Euro, Euro I and Euro 2/II vehicles) which enter London each year (i.e. the number of vehicles operating in London).

164. The costs to operators have been calculated using estimated replacement, or abatement equipment costs, combined with estimates of the number of vehicles operating in London from the phase 2 feasibility report. This analysis takes the natural retirement of vehicles in the fleet into account. The possible responses of the operators includes replacing older vehicles with either new or second hand vehicles, re-engining, fitting abatement equipment (particulate filters to address PM or selected catalytic reduction to address NO_X), or moving vehicles fleets to switch older vehicles away from London. Stakeholder consultation within the phase 2 study indicated that some 25% of operators would take this latter option (which is a zero cost option). For other non-compliant vehicles, a range of operator responses have been assumed, depending on the existing Euro standard (age of the vehicle) and the vehicle type (recognising that some specialist vehicles, such as coaches, have longer lifetimes due to the high capital costs).

[27] Costs to Operators of Low Emission Zone (LEZ) Scenarios for the Air Quality Review by AEA Technology Environment and LEZ scheme Standardisation of Cost by TTR.

165. The analysis has been used to estimate the NPV and annualised costs of the theoretical London scheme on operators. The possible costs of the theoretical London LEZ scheme are outlined in Table 3.63 below.

Table 3.63: Possible annual present value of costs to operators for Measure G1 (£millions)

	Low estimate	High estimate
Estimated costs to operators	14	40

Costs and benefits of Measure G1

166. Table 3.64 below presents the annual Net Present Value (NPV) of Measure G1, which is the annual benefits minus the annual costs. This is based on a 6% hazard rate reduction, for chronic mortality effects, and a range in possible lag times (0 or 40 years lag), as explained in Chapter 2.

167. The analysis shows that for benefits in London from the scheme, the present value of costs exceeds benefits under all assumptions. However, looking at the first phase of the scheme in isolation underestimates the benefits of the LEZ, as it attributes the scheme set-up costs to the first phase only. More importantly, only the benefits of the LEZ in London have been estimated. The benefits outside London are potentially very significant. Some scoping analysis has indicated that the benefits outside London could be large (£0.6 to £5.2 million annualised benefit). The analysis has included these benefits outside London, and the potential noise benefits from the first phase of the LEZ (see discussion of noise benefits above) which are estimated at £1 – £2 million in the first year of the scheme. With these additional categories included, the benefits and costs of the scheme are approximately equal for the low estimate of costs and the 6% hazard rate with no lag (although the costs still slightly exceed the benefits).

Table 3.64: Annual costs and benefits of implementing Measure G1 (£millions)[a]

	Annual PV of Costs	Annual PV of Benefits	Annual NPV
London AQ only	18 – 45	8 – 12	(37) – (7)
Total b	18 – 45	12 – 17	(33) – (1)

[a] Numbers in brackets represent negative values.

[b] Includes estimate of benefits to noise, and for air quality outside London.

Benefits of Measure G2

168. The emissions benefits of this measure are again based on the TfL London phase 2 feasibility study, and have been calculated using the damage cost estimates outlined in Chapter 2.

169. The benefits have been assessed over a 5 year period from 2010 to 2014, using the damage cost methodology described in Chapter 2 i.e. applying the relevant per tonne damage cost to the change in emissions each year between 2010 and 2014.

170. The change in emissions in 2010 are shown in Table 3.65 and the resultant quantified health impacts are shown in Table 3.66.

Table 3.65: Change in emissions by implementing Measure G2

Country	Pollutant	Emissions Saved (tonnes)		
		2010	2015	2020
UK	PM_{10}	229	0	0
	NO_x	829	0	0

Table 3.66: Quantified impacts of implementing Measure G2

PM life years saved ('000s) – 6% (2007 - 2014)	PM – RHA (2010 p.a.)	PM – CHA (2010 p.a.)
5 – 6	14	14

171. Benefits have been estimated in the first year and in subsequent years to give an accurate profile of emissions above the baseline over time. Table 3.67 below presents the benefits for the phase 2 of the scheme only (from 2010 to 2014).

Table 3.67: Annual present value of impacts of implementing Measure G2 (£millions)

PM life years saved ('000s) – 6%	PM – RHA	PM – CHA
17 – 25	0.02 – 0.08	0.02 – 0.08

172. The scheme will also lead to benefits outside London, from a cleaner fleet operating across other areas. These benefits have been estimated, based on initial work undertaken to progress the implementation of the actual London LEZ. These imply additional annualised benefits outside London of £1 to £5 million per annum, using the AQS review damage costs. There are no additional noise benefits predicted for the second phase of the LEZ, as the noisier vehicles from the fleet have already been excluded in phase 1.

Costs of Measure G2

173. The scheme costs of the second phase of the theoretical London LEZ will follow from the estimates above, with similar operating costs to the phase 1 study.[28]

174. More important is the costs to operators. Costs have been calculated with a new baseline of vehicles, adjusted for the operator response to phase 1 of the scheme. Operators may have considered the effects of both schemes together in their response to phase 1 of the theoretical LEZ in 2007. If phase 2 of the theoretical scheme is introduced in London, the costs of this measure are added to the costs of the phase 1 considered above.

[28] In practice, the operating costs will change due to the numbers of vehicles in the scheme. Chapter 3 Cost and benefits of additional measures

175. The annualised costs of the second phase (only) are presented in Table 3.68 below. The estimated costs to operators rises in 2010, as the proposed zone is tightened up to a Euro III + RPC zone (which has implications for additional NO_X abatement for vehicles).

Table 3.68: Possible annual present value of costs to operators for Measure G2 (£millions)

5 years (2010 – 2014)	Low estimate	High estimate
Estimated costs to operators	33	88

Costs and benefits of Measure G2

176. Table 3.69 below presents the annual net present value (NPV) of Measure G2, which is the annual benefits minus the annual costs. This is based on a 6% hazard rate reduction, for chronic mortality effects, and a range in possible lag times (0 or 40 years lag), as explained in Chapter 2.. The analysis shows that the present value of costs exceeds benefits under all measures. However, only the benefits of the theoretical LEZ in London have been estimated. The theoretical London LEZ would also have benefits outside London, which are potentially very significant. Some scoping analysis has indicated that the benefits outside London could be large and the analysis has included these outside London benefits. When these are added, the costs and benefits of the scheme are similar between the low estimate of costs, and the 6% hazard rate with no lag.

Table 3.69: Annual costs and benefits of implementing Measure G2 (£millions)[a]

	Annual PV of Costs	Annual PV of Benefits	Annual NPV
London AQ only	33 – 88	18 – 26	(70) – (6)
Total[b]	33 – 88	21 – 31	(67) – (2)

[a] Numbers in brackets represent negative values.

[b] Includes estimate of benefits to noise, and for air quality outside London.

Benefits of Measure G3

177. This scheme applies the same theoretical London LEZ phase 1 criteria to the other 7 largest cities in the UK. The implementation data is later (2010), to take account of the work that would be needed to set-up such a scheme.

178. The emissions benefits of this measure are again based on the London phase 2 feasibility study, and have been calculated using the damage cost estimates outlined in Chapter 2.

179. The benefits have been assessed over an 8 year period from 2010 to 2017, using the damage cost methodology described in Chapter 2 i.e. applying the relevant per tonne damage cost to the change in emissions each year between 2010 and 2017.

180. The change in emissions in 2010, 2015 and 2020 are shown in Table 3.70 and the resultant quantified health impacts are shown in Table 3.71.

Table 3.70: Change in emissions by implementing Measure G3

Country	Pollutant	Emissions Saved (tonnes)		
		2010	2015	2020
UK	PM_{10}	150	35	0
	NO_x	461	108	0

Table 3.71: Quantified impacts of implementing Measure G3

PM life years saved ('000s) – 6% (2010 - 2017)	PM – RHA (2010 p.a.)	PM – CHA (2010 p.a.)
2	5	5

181. The benefits of this measure are based on the work undertaken by Netcen, and have been calculated using the damage costs. Benefits have been estimated in year 1 and in subsequent years to give an accurate profile of emissions above the baseline over time. Table 3.72 presents the benefits for the Phase 1 of the 7 city scheme, showing the benefits in the 7 cities only.

Table 3.72: Annual present value of impacts of implementing Measure G3 (£millions)

PM life years saved ('000s) – 6%	PM – RHA	PM – CHA
5 – 7	0.004 – 0.02	0.004 – 0.02

182. The benefits are lower than the theoretical London scheme in 2007. There are two reasons for this. Firstly, and most importantly, the delay of the scheme by three years (to 2010) significantly reduces the benefits of the LEZ – because there are much lower benefits relative to the baseline (there are less high polluting, older vehicles, so the LEZ benefit is lower). Secondly, per tonne of emission reduced, there are lower benefits in the other seven areas relative to London (because emission reductions in London are in an extremely large urban area with high population density, and so correspondingly much higher damage costs).

183. However, there would be additional benefits outside the seven areas. It has not been possible to quantify these, though they could be significant (consistent with the findings for London above). It is highlighted that a theoretical LEZ scheme that included London and the other 7 largest cities would have a significant national impact. In practical terms, this might effectively constitute a national scheme. Therefore the benefits above might be a significant underestimate of the scheme potential.

Costs of Measure G3

184. The estimated scheme costs of this measure have been estimated by TTR. The costs vary by the type of scheme introduced, whether manually or automatically enforced. The start-up costs are estimated to be £25 million, with annual operating costs of £7 million (based on fixed plus mobile camera scheme). This includes some shared facilities with the London scheme (e.g. on registering vehicles), which improves the cost-effectiveness of these schemes relative to London alone. The values are presented below in Table 3.73.

185. The costs to operators in this measure are based on an initial analysis of the possible number of operators vehicles affected in the seven cities. The estimated costs of this option in 2010 are shown below. These costs are extremely sensitive to the number of vehicles affected. Unfortunately there are no estimates of the number of vehicles operating in each of the 7 cities. Therefore the estimate is based on the number of vehicles operating in London, scaled to each city using vehicle km activity data for the individual cities and London. The confidence in these estimates is therefore low.[29] If it was assumed that the extension to the seven other areas might effectively constitute a national scheme, i.e. if the actual number of operators affected was much higher, then these costs would increase very significantly.

Table 3.73: Annual present value of impacts of implementing Measure G3 (£millions)

Annual PV of Costs – Scheme Costs	Annual PV of Costs – Costs to Operators
9	10

Costs and benefits of Measure G3

186. Table 3.74 below presents the annual Net Present Value (NPV) of Measure G3, which is the annual benefits minus the annual costs. This is based on a 6% hazard rate reduction, for chronic mortality effects, and a range in possible lag times (0 or 40 years lag), as explained in Chapter 2.

Table 3.74: Annual costs and benefits of implementing Measure G3 (£millions)[a]

Annual PV of Costs	Annual PV of Benefits	Annual NPV
19	5 – 7	(14) – (12)

[a] Numbers in brackets represent negative values.

187. The analysis shows that the present value of costs exceeds benefits under all measures, for scheme costs alone, and for scheme and operating costs. However, the analysis does not include the additional benefits from vehicles travelling outside the 7 cities across the national road network. These benefits could be considerable (e.g. based on the relative size of benefits outside the theoretical London scheme), though they

[29] In practice, some of the vehicles that are affected by the London phase 1 scheme will be the same vehicles that are operating in these other seven areas. Therefore, costs to operators may actually be lower – though this would also mean that benefits would not be additional to the estimated London scheme's benefits outside London, quantified for the G1 and G2 schemes.

would be unlikely to change the net present value of the scheme such that benefits exceeded costs. It is possible that the combination of the theoretical London plus 7 city schemes could effectively constitute a national scheme. In such a case the benefits would be much higher, but the costs to operators would also rise accordingly.

3.2.9 Measure H: Retrofitting scheme

188. Diesel Particulate Filters (DPFs) can be retrofitted to HGVs and the captive fleet (coaches and buses) in order to greatly reduce the emissions of PM from vehicles already in the fleet. This measure is not concerned with new vehicle purchases, but rather with vehicles that are already in the fleet but that are not meeting Euro V standards. This measure is assumed to come into effect in 2006.

189. The scheme was considered for two forms of DPF technologies. The differences between the two technologies are in their operational requirements:

- DPF1: This technology includes DPF fitted with a Fuel Borne Catalyst (FBC), usually metal based, to lower particulate combustion temperature. This technology has an annual additive cost.
- DPF2: This is the Catalyst Based DPF. This filter incurs no annual additive costs.

190. Percentage uptake rates of the incentive in the fleet are presented in Table 3.75. These uptake rates were determined ex ante by consideration of what would be realistic and technologically feasible. Two different uptake rates are looked at for DPF2, reflecting uncertainty over what would be technologically feasible.

Table 3.75: Percentage uptake of incentive in the fleet of buses, coaches and HGVs

	2006	2007	2008	2009	2010	2011	2012
Measure H1: Uptake rate for DPF1	2.6%	18.2%	33.8%	49.4%	65.0%	65.0%	65.0%
Measure H2: Uptake rate for DPF 2	3%	7%	11%	16%	20%	20%	20%
Measure H3: Uptake rate for DPF 2	3%	11%	19%	27%	35%	35%	35%

Benefits and costs of Measure H

191. The benefits and costs of this measure depend on the uptake rates of the incentive shown above as well as the change in emissions using the different versions of the DPF technology. The costs and benefits of this measure is thus presented in the following three sections:

- **Measure H1:** This measure considers the benefits and costs from the implementation of the DPF 1 technology using the uptake rates described in Table 3.75 above.
- **Measure H2:** This measure considers the benefits and costs from the implementation of the DPF 2 technology using the uptake rate shown in the Table 3.75 above
- **Measure H3:** This measure considers the benefits and costs from the implementation of the DPF 2 technology using the uptake rate shown in the Table 3.75 above

Benefits of Measure H1

192. This measure was assessed on the basis of emissions changes only; no detailed concentrations modelling was undertaken. The emissions reductions from this technology and uptake rate is given in Table 3.76 below.

Table 3.76: Change in emissions by implementing Measure H1

Country	Pollutant	Emissions Saved (tonnes)		
		2010	2015	2020
UK	PM_{10}	1,949	467	65

193. The carbon impact of this measure is dependent on the impacts of the filter on the fuel economy of vehicles. Following discussions with industry and additional information from consultation responses Measure H1 is no longer assumed to have an impact on fuel economy. Table 3.77 below presents the revised fuel economy assumptions alongside the previous improvements in fuel economy once the traps are fitted, assumed in the original report. As a result this measure no longer has a carbon impact.

Table 3.77: Fuel economy assumptions by vehicle type for Measure H1

Vehicle Type	Original fuel economy impact	Revised fuel economy impact
Rigid HGV	+ 1%	0%
Articulated HGV	+ 1%	0%
Captive Fleet	+ 1%	0%

194. The damage cost methodology described in Chapter 2 also provides estimates of the physical impacts per tonne of pollutant. The quantified health and non-health benefits have therefore been calculated by applying these per tonne estimates to the relevant change in emissions. The 2010 change in emissions is assumed to apply between 2010 and 2014, the 2015 change in emissions is assumed to apply between 2015 and 2019 and the 2020 change in emissions is assumed to apply between 2020 and 2022. Measure H1 does not have a lasting impact as the emission reductions only last until the end of the life of the vehicle/technology. Therefore the change in emissions as a result of this measure is close to zero by 2020. Table 3.78 illustrates the health impacts generated by the above changes in emissions.

Table 3.78: Quantified impacts of implementing Measure H1

PM life years saved ('000s) – 6% (2010 - 2022)	PM – RHA (2010 p.a.)	PM – CHA (2010 p.a.)
25 – 27	34	34

195. These monetary benefits have then been estimated using the per tonne damage costs described in Chapter 2. The relevant annual damage cost estimate has been applied to the changes in emissions between 2010 and 2022, assuming that the 2010 change in emissions applies between 2010 and 2014, the 2015 change in emissions applies between 2015 and 2019 and the 2020 change in emissions applies between 2020 and 2022.

Table 3.79: Annual present value of impacts of implementing Measure H1 (£millions)

PM life years saved ('000s) – 6%	PM – RHA	PM – CHA
35 – 51	0.03 – 0.15	0.03 – 0.16

Costs of Measure H1

196. The costs of this measure are as follows:

- *Technology costs:* The unit costs of the DPF technology and the operational costs for the different vehicle types are outlined in Table 3.80 below. The costs presented are the costs per unit of producing the technology. These costs have been revised downwards taking into account better information received during the consultation period. The costs are annualised over the lifetime of the measure taking into account the vehicle survival rates.

Table 3.80: Resource costs per unit of technology for Measure H1 (2005 prices)

Vehicle Type	Type of Technology	Unit Resource costs	Annual Cleaning costs	Annual Additive cost
Articulated HGVs	DPF 1	£1,750	£240	£338
Rigid HGVs	DPF 1	£1,350	£160	£135
Captive Fleet	DPF 1	£1,350	£160	£135

- *Resource costs of fuel:* As discussed above this DPF technology is no longer assumed to have a fuel economy impact. As a result the resource costs of fuel for this measure is zero.
- *Welfare impacts of the changes in fuel economies:* There are no longer welfare impacts associated with the change in fuel economy given the change in fuel economy assumption set out above.

197. The costs of this measure as described above are discounted at the standard Green Book rate and annualised over the lifetime of this measure (2006 – 2022) and presented in Table 3.81 below.

Table 3.81: Costs of implementing Measure H1 in the UK in 2005 prices (£millions)

Annualised Technology Costs	Annualised Resource cost of extra fuel consumed	Annualised Welfare impact due to rebound effect	Annual PV of Costs
24	44	0	68

Costs and benefits of Measure H1

198. Table 3.82 below presents the annual Net Present Value (NPV) of Measure H1, which is the annual benefits minus the annual costs. This is based on a 6% hazard rate reduction, for chronic mortality effects, and a range in possible lag times (0 or 40 years lag), as explained in Chapter 2.

Table 3.82: Annual costs and benefits of implementing Measure H1 in the UK (£millions)[a]

Annual PV of Costs	Annual PV of Benefits	Annual NPV
68	35 – 51	(33) – (17)

[a] Numbers in brackets represent negative values.

199. From the above table it can be noted that the annualised costs of this measure outweigh the annualised benefits. Further sensitivity analysis of the impacts of the NPV of this measure when costs are changed is presented in Chapter 5.

Benefits of Measure H2

200. The emissions reductions from this technology are given in Table 3.83 below.

Table 3.83: Change in emissions by implementing Measure H2

Country	Pollutant	Emissions Saved (tonnes)		
		2010	2015	2020
UK	PM_{10}	533	124	14

201. The carbon impact of this measure is dependent on the impacts of the filter on the fuel economy of vehicles. Following discussions with industry and additional information from consultation responses Measure H2 is no longer assumed to have an impact on fuel economy. The table below presents the revised fuel economy assumptions alongside the previous improvements in fuel economy once the traps are fitted, assumed in the original report. As a result this measure no longer has a carbon impact.

Table 3.84: Fuel economy assumptions by vehicle type for Measure H2

Vehicle Type	Original fuel economy impact	Revised fuel economy impact
Rigid HGV	+ 1%	0%
Articulated HGV	+ 1%	0%
Captive Fleet	+ 1%	0%

202. The health and non-health benefits have been estimated in the same way as for Measure H1. Table 3.85 illustrates the health impacts generated by the above changes in emissions.

Table 3.85: Quantified impacts of implementing Measure H2[a]

PM life years saved ('000s) – 6% (2010 - 2022)	PM – RHA (2010 p.a.)	PM – CHA (2010 p.a.)
7	9	9

203. Annual damage costs estimates have been used to assess the monetary impacts as described for Measure H1.

Table 3.86: Annual present value of impacts of implementing Measure H2 £millions)[a]

PM life years saved ('000s) – 6%	PM – RHA	PM – CHA
10 – 14	0.01 – 0.04	0.01 – 0.04

Costs of Measure H2

204. The costs of this measure are as follows:

- *Costs of technology:* The unit costs of the DPF technology and the operational costs for the different vehicle types are outlined in Table 3.87 below. These costs have been revised downwards taking into account better information received during the consultation period. The costs presented are the resource costs per unit which the producers have to incur when producing the equipment. It is assumed that the costs are passed on in full to the purchasers of the vehicles.

Table 3.87: Resource costs per unit of technology for Measure H2 (2005 prices)

Vehicle Type	Type of Technology	Unit Resource costs	Annual Cleaning costs	Annual Additive cost
Articulated HGVs	DPF 2	£1,750	£240	0
Rigid HGVs	DPF 2	£1,350	£160	0
Captive Fleet	DPF 2	£1,350	£160	0

- *Resource costs of fuel:* As discussed above this DPF technology is no longer assumed to have a fuel economy impact. As a result the resource costs of fuel for this measure is zero.
- *Welfare impacts of the changes in fuel economies:* There are no longer welfare impacts associated with the change in fuel economy given the change in fuel economy assumption set out above.

205. The costs of this measure as described above are discounted at the standard appropriate HM Treasury Green Book rate and annualised over the lifetime of this measure (2006 – 2022) and presented in Table 3.88 below

Table 3.88: Costs of implementing Measure H2 in the UK in 2005 prices (£millions)

Annualised Technology Costs	Annualised Resource cost of extra fuel consumed	Annualised Welfare impact due to rebound effect	Annual PV of Costs
7	7	0	14

Costs and benefits of Measure H2

206. Table 3.89 below presents the annual Net Present Value (NPV) of Measure H2 i.e. the annual benefits minus the annual costs. This is based on a 6% hazard rate reduction, for chronic mortality effects, and a range in possible lag times (0 or 40 years lag), as explained in Chapter 2.

Table 3.89: Annual costs and benefits of implementing Measure H2 in the UK (£millions)[a]

Annual PV of Costs	Annual PV of Benefits	Annual NPV
14	10 – 14	(5) – 0

[a] Numbers in brackets represent negative values.

207. The results in Table 3.89 above indicate that the costs outweigh the benefits of Measure A2 when the 6% hazard rate is used for the 40 year lag scenario. However for the no-lag scenario, the benefits slightly outweigh the costs. The latest statements from COMEAP suggest that, although evidence was limited, the Committee's judgement tends towards a greater proportion of the effect occurring in the years sooner after the pollution reduction rather than later. This would mean that the effect is more likely to be nearer the no lag result. Further sensitivity analysis of the impacts of the NPV of this measure when costs are changed is presented in Chapter 5.

Benefits of Measure H3

208. The emissions reductions from this technology is given in Table 3.90 below.

Table 3.90: Change in emissions by implementing Measure H3

Country	Pollutant	Emissions Saved (tonnes)		
		2010	2015	2020
UK	PM_{10}	1,005	238	31

209. The carbon impact of this measure is dependent on the impacts of the filter on the fuel economy of vehicles. Following discussions with industry and additional information from consultation responses Measure H2 is no longer assumed to have an impact on fuel economy. The table below presents the revised fuel economy assumptions alongside the previous improvements in fuel economy once the traps are fitted, assumed in the original report. As a result this measure no longer has a carbon impact.

Table 3.91: Fuel economy assumptions by vehicle type for Measure H3

Vehicle Type	Original fuel economy impact	Revised fuel economy impact
Rigid HGV	+ 1%	0%
Articulated HGV	+ 1%	0%
Captive Fleet	+ 1%	0%

210. The quantified health and non-health benefits have been calculated using the same method as for Measure H1. Table 3.92 illustrates the health impacts generated by the above changes in emissions.

Table 3.92: Quantified impacts of implementing Measure H3[a]

PM life years saved ('000s) – 6% (2010 - 2022)	PM – RHA (2010 p.a.)	PM – CHA (2010 p.a.)
13 – 14	17	18

211. The damage cost estimates described in Chapter 2 have then been used to assess the monetary impact of Measure H3, using the same method as Measure H1. These values are presented in Table 3.93 below.

Table 3.93: Annual present value of impacts of implementing Measure H3 £millions)[a]

PM life years saved ('000s) – 6%	PM – RHA	PM – CHA
18 – 26	0.02 – 0.08	0.02 – 0.08

Costs of Measure H3

212. The costs of this measure are as follows:

- Costs of technology: The unit costs of the DPF technology and the operational costs for the different vehicle types are outlined in Table 3.94 below. These costs have been revised downwards taking into account better information received during the consultation period. The costs presented are the resource costs per unit which the producers have to incur when producing the equipment. It is assumed that the costs are passed on in full to the purchasers of the vehicles.

Table 3.94: Resource costs per unit of technology for Measure H3 (2005 prices)

Vehicle Type	Type of Technology	Unit Resource costs	Annual Cleaning costs	Annual Additive cost
Articulated HGVs	DPF 2	£1,750	£240	0
Rigid HGVs	DPF 2	£1,350	£160	0
Captive Fleet	DPF 2	£1,350	£160	0

- *Resource costs of fuel:* As discussed above this DPF technology is no longer assumed to have a fuel economy impact. As a result the resource costs of fuel for this measure is zero.
- *Welfare impacts of the changes in fuel economies:* There are no longer welfare impacts associated with the change in fuel economy given the change in fuel economy assumption set out above.

213. The costs of this measure as described above are discounted at the standard HM Treasury Green Book rate and annualised over the lifetime of this measure (2006 – 2022) and presented in Table 3.95 below

Table 3.95: Costs of implementing Measure H3 in the UK in 2005 prices (£millions)

Annualised Technology Costs	Annualised Resource cost of extra fuel consumed	Annualised Welfare impact due to rebound effect	Annual PV of Costs
13	12	0	25

Costs and benefits of Measure H3

214. Table 3.96 below presents the annual Net Present Value (NPV) of Measure H3, that is the annual benefits minus the annual costs. This is based on a 6% hazard rate reduction, for chronic mortality effects, and a range in possible lag times (0 or 40 years lag), as explained in Chapter 2.

Table 3.96: Annual costs and benefits of implementing Measure H3 in the UK (£millions)[a]

Annual PV of Costs	Annual PV of Benefits	Annual NPV
25	18 – 26	(7) – 2

[a] Numbers in brackets represent negative values.

215. The results in Table 3.96 above indicate that the costs outweigh the benefits of Measure A2 when the 6% hazard rate is used for the 40 year lag scenario. However for the no-lag scenario, the benefits slightly outweigh the costs. The latest statements from COMEAP suggest that, although evidence was limited, the Committee's judgement tends towards a greater proportion of the effect occurring in the years sooner after the pollution reduction rather than later. This would mean that the effect is more likely to be nearer the no lag result. Further sensitivity analysis of the impacts of the NPV of this measure when costs are changed is presented in Chapter 5.

3.3 Costs and benefits of industrial, domestic and shipping measures

216. This section presents the industrial, domestic and shipping measures considered for the Air Quality Strategy. This section considers only the monetary estimates of the impacts of these measures, the non-monetised impacts are described qualitatively in Chapter 4 of this report.

217. The measures presented in this section include:

- **Measure I:** The replacement of coal for domestic use in the UK for either natural gas or oil, depending on the availability of natural gas;
- **Measure J:** Tighter NO_X product standards for domestic gas fired appliances;
- Measure K: The implementation of SCR equipment on power stations, iron and steel plants and petroleum refineries from 2010;
- **Measure L:** A requirements on small combustion plants for a 50% reduction in NO_2 and SO_2 emissions;
- **Measure M:** A measure to reduce VOCs emissions by 10%; and
- **Measure N:** A shipping measure that requires the global shipping fleet to use 1% sulphur fuels and reduce NO_X emissions by 25%.

3.3.1 Measure I: Domestic combustion – switch from coal to natural gas or oil

218. Measure I would require households to purchase a gas or oil boiler to replace their existing coal-fired boiler and would come into effect in 2010. Burning natural gas and oil in domestic boilers for heating generates fewer emissions of PM_{10} and NO_x than the equivalent boilers that burn coal.

219. Under Measure I, 70% of coal-burning domestic boilers in Great Britain would be replaced by boilers burning natural gas and the remaining 30% of coal boilers would be replaced by boilers burning oil. Due to the lack of availability of natural gas infrastructure in Northern Ireland, it is assumed that in Northern Ireland 70% of the coal-burning boilers would be replaced by oil boilers and 30% would be replaced by natural gas boilers.

Benefits of Measure I

220. The reduction in emissions for this measure were estimated by Netcen using the difference in emission factors between the different types of boilers. The amount of emissions (tonnes) that are saved in 2010, 2015 and 2020 by switching away from coal-burning boilers in each country is illustrated in Table 3.97 below.

Table 3.97: Change in emissions by implementing Measure I for the UK

Country	Pollutant	Emissions Saved (tonnes)		
		2010	2015	2020
UK	PM_{10}	1,554	673	32
	NO_x	(4)	(2)	0
	SO_2	2,568	1,112	53

221. Measure I should be seen in the context of a general underlying trend away from coal-burning domestic boilers; it will therefore have a relatively short term impact as it will have the effect of accelerating the existing trend. The effect of the measure has therefore been assessed over a 15 year period between 2010 and 2024.

222. Detailed concentration mapping of the PM_{10}, NO_X emissions and resulting ozone concentrations was not carried out for this measure. Therefore, in order to calculate the benefits of the above reductions in emissions, the damage cost methodology has been used, as described in Chapter 2. The relevant damage cost for each year has been applied to the emission estimates; given that there are only emissions estimates for 2010, 2015 and 2020 it is assumed that the 2010 emissions reductions apply between 2010 and 2014, the 2015 emissions reductions apply between 2015 and 2019 and the 2020 emissions reductions apply between 2020 and 2024.

223. Based on the damage costs analysis, it is possible to estimate the detailed health impacts of a unit reduction in PM_{10} and NO_X emissions. Table 3.98 illustrates the impacts generated by the emission reductions of Measure I. Measure I also has a positive impact on carbon emissions, as gas has much lower carbon emissions.

Table 3.98: Quantified impacts of implementing Measure I[a]

PM life years saved ('000s) – 6% (2010 – 2024)	PM – RHA (2010 p.a.)	PM – CHA (2010 p.a.)	SO_2 as gas[b] – Mortality (2010 p.a.)	SO_2 as gas[b] – RHA (2010 p.a.)	Carbon ('000s tonnes p.a.) (2010)
13 – 15	16	16	6	5	29

[a] Data presented in the table in brackets represents a negative impact.

[b] This relates to the direct effects of SO_2 as a gas rather than the effects of SO_2 as a precursor of sulphate (the latter is covered under the PM health effects).

224. Applying the damage cost methodology also provides monetary estimates of the benefits. The annual present value in 2005 of the range of benefits is shown in Table 3.99 below. These monetised impacts include the reduction to buildings damage, as well as the health impacts, due to the decreased emissions.

Table 3.99: Annual present value of impacts of implementing Measure I (£millions)[a]

PM life years saved – 6%	PM – RHA	PM – CHA	SO_2 as gas – Mortality	SO_2 as gas – RHA	Carbon	Buildings & materials
18 – 26	0.02 – 0.09	0.02 – 0.09	0.01 – 0.02	0.01 – 0.02	2	0.26

[a] Numbers in brackets represent negative values.

Costs of Measure I

225. The capital costs of Measure I are based on the additional costs of domestic appliances. As of 1 April 2005 the boiler provisions in the revised Building Regulations for England and Wales require existing boilers to be replaced by boilers with a SEDBUK A or B rating. Hence, it is assumed for this measure that replacement boilers will be new condensing boilers with an assumed average cost of £800 (Heat and Plumb website (www.heatandplumb.com) and Department of Trade and Industry, 2000). Oil boilers are assumed to incur the same cost. No net change in fuel costs is assumed, so incremental operating costs are zero. In practice, the new boilers are more fuel efficient but there was insufficient information to cost the fuel saving. Installation costs are assumed to be £1,000 per household.

226. The additional infrastructure costs (such as new gas pipelines) of increasing the availability of natural gas and oil to those households currently using solid fuel boilers has not been included. For places where it would not be realistic to extend the gas supply network, this measure therefore assumes the switching to oil or the use of LPG cylinders.

227. The share of households using coal for space and water heating in the UK in 2005 is estimated to be 1.5% (Department of Trade and Industry, 2000),[30] and the number of households in the UK is estimated to be 22.6 million and the number of boilers that are replaced are 339,000.

228. The cost figures for Measure I are presented in Table 3.100 below:

Table 3.100: Costs of implementing Measure I in the UK in 2005 prices (£millions)

Lifetime of Technology (years)	Capital Cost (2005 prices)	Operating Cost (2005 prices)	Annual PV of Costs
15	610	0	43

Cost and benefits of Measure I

229. Table 3.101 below presents the annual Net Present Value (NPV) of Measure I, that is the annual benefits minus the annual costs of Measure I. This is based on a 6% hazard rate, for chronic mortality effects, and a range in possible lag times (0 or 40 years lag), as explained in Chapter 2.

Table 3.101: Annual costs and benefits of implementing Measure I in the UK (£millions)[a]

Annual PV of Costs	Annual PV of Benefits	Annual NPV
43	20 – 28	(23) – (15)

[a] Numbers in brackets represent negative values.

230. The results in Table 3.101 above indicate that the costs outweigh the benefits of Measure I.

231. As indicated in the discussion of the costs and benefits of Measure I above, a number of areas could benefit from further research. These are:

- Detailed concentration mapping would improve the calculation of the benefits;
- Any change in operating costs; and
- The infrastructure costs of increasing the availability of natural gas supply.

3.3.2 Measure J – Domestic Combustion: Tighter NO_X product standards for gas fired appliances

232. Measure J imposes a minimum NO_X emissions standard on household gas fired boilers post 2008. The CEN standard for gas boilers, EN 483, allows five NO_X emission classes. Presently Building Regulations do not specify a NO_X class. Under this measure gas boilers installed would have to meet one of the highest two NO_X classes, that is a class 4 or 5. This measure is applicable across the UK and is assumed to also apply across the EU.

[30] 'Energy Paper 68 (EP68) Energy Projections for the UK', Department of Trade and Industry (2000). Available at http://www.dti.gov.uk/energy/inform/energy_projections/index.shtml

233. The higher standard boilers would be installed at the natural replacement rate of boilers, which is assumed to be 5% a year. The number of households in the UK is assumed to be 22.6 million. The maximum uptake of condensing boilers has also been limited to 95% due to constraints that some households may have regarding drainage.

Benefits of Measure J

234. The reduction in emissions for this measure was estimated by Netcen using the difference in NO_X emission factors between the CEN483 Class 4 boilers and a boiler that meets the current minimum standard (SEDBUK A or B)

235. Detailed concentration mapping of the NO_X emissions, resulting secondary particulate matter concentrations and resulting ozone concentrations was carried out in order to calculate the benefits of this measure (the methodology for the mapping has been described in more detail in Chapter 2 and the consultation document). Table 3.102 shows the reduction in the population weighted concentrations compared to the baseline (i.e. the emissions that would have occurred had the boilers been replaced with higher NO_X boilers) for each country in 2010, 2015 and 2020.

Table 3.102: Change in concentrations by implementing Measure J for the UK disaggregated by country

Country	Pollutant	Concentration changes relative to baseline ($\mu g.m^{-3}$)a		
		2010	2015	2020
England	PM_{10}	(0.008)	(0.022)	(0.025)
	NO_2	(0.082)	(0.238)	(0.405)
	Ozone	0.004 – 0.039	0.012 – 0.108	0.024 – 0.184
Northern Ireland	PM_{10}	(0.003)	(0.010)	(0.011)
	NO_2	(0.012)	(0.041)	(0.067)
	Ozone	0.001 – 0.015	0.006 – 0.039	0.008 – 0.066
Scotland	PM_{10}	(0.003)	(0.010)	(0.011)
	NO_2	(0.068)	(0.200)	(0.342)
	Ozone	0.002 – 0.028	0.008 – 0.076	0.015 – 0.127
Wales	PM_{10}	(0.005)	(0.017)	(0.019)
	NO_2	(0.051)	(0.158)	(0.284)
	Ozone	0.002 – 0.019	0.007 – 0.052	0.013 – 0.086
UK	PM_{10}	(0.006)	(0.020)	(0.023)
	NO_2	(0.077)	(0.225)	(0.384)
	Ozone	0.004 – 0.037	0.011 – 0.101	0.022 – 0.171

[a] Ozone concentration changes shown as a range incorporating results assuming both a zero threshold and a 50ppb threshold. PM_{10} concentrations are presented in ($\mu g.m^{-3}$, gravimetric).

236. The quantified health and non-health benefits have been calculated from the resulting concentrations using the methodology described in Chapter 2. Measure J will have a long term impact as once replaced, all household boilers will be emitting less NO_X. Hence, the benefit analysis is calculated on the assumption of a sustained pollution reduction to 2109. Table 3.103 illustrates the health impacts generated by the changes in concentrations generated by Measure J.

237. It was not possible to calculate the difference in fuel efficiency between the different boiler standards, hence it has not been possible to measure the impact of Measure J on carbon emissions.

Table 3.103: Quantified impacts of implementing Measure J[a]

PM life years saved ('000s) – 6% (2010 – 2109)	PM – RHA (2020 p.a.)	PM – CHA (2020 p.a.)	Ozone mortality (2020 p.a.)	Ozone RHA (2020 p.a.)
48 – 92	8	8	(59) – (8)	(68) – (9)

[a] at a presented in the table in brackets represents a negative impact – for ozone impacts this reflects the increase in population weighted ozone concentrations presented in the previous table.

238. These benefits have then been monetised using the methodology described in Chapter 2 and discounted to generate a Present Value (PV) in 2005 prices of the different impacts. This present value has then been annualised. The monetary values can be seen in Table 3.104 below. These monetised impacts include the impacts on crop yields and damage to materials avoided due to the reduction in concentrations.

Table 3.104: Annual present value of impacts of implementing Measure J (£millions)[a]

PM life years saved – 6%	PM – RHA	PM – CHA	Ozone Mortality	Ozone RHA	Crops	Buildings & materials
20 – 48	0.03 – 0.12	0.03 – 0.12	(1) – (0.04)	(1) – (0.03)	(0.20)	(0.40)

[a] Numbers in brackets represent negative values.

Costs of Measure J

239. The capital costs of Measure J are based on the cost differential between an average size new boiler that meets the tighter NOX standards and an average size boiler that meets the minimum standards (SEDBUK A or B). This cost differential is expected to be around £200. Measure J assumes that the boilers are replaced at their natural rate, hence no installation costs are applicable as they would have been incurred under the baseline as well. Energy efficiency savings are expected from this measure. The scale of energy efficiency gains, over and above the baseline, are therefore currently not clear. Hence these gains have not been quantified and the additional operating costs are assumed to be zero. The approach adopted here, of just using the difference in capital costs, is therefore likely to overestimate the costs.

240. The replacement rate of boilers is assumed to be 5 per cent, but the maximum uptake of condensing boilers is assumed to be 95 per cent. The number of households in the UK is estimated to be 22.6 million, hence the number of boilers that are replaced annually is around 1.073 million.

241. In order to calculate the benefits of this measure it is assumed that the implementation of this measure leads to a sustained reduction in pollution. To be consistent with the benefits profile, the costs have therefore been modelled to 2109. It is therefore assumed that the annual capital costs of £216 million are incurred throughout the period 2008-2109. This stream of costs is then discounted back to 2005 (using the approach discussed in Chapter 2) to estimate the present value of the costs. This present value has then been annualised and the results are illustrated in Table 3.105 below.

Table 3.105: Costs of implementing Measure J in the UK in 2005 prices (£millions)

Lifetime of Technology (years)	Capital Cost (2005 prices)	Operating Cost (2005 prices)	Annual PV of Costs
20	216	0	196

Cost and benefits of Measure J

242. Table 3.106 below presents the annual Net Present Value (NPV) of Measure J, that is the annual benefits minus the annual costs of Measure J. This is based on a 6% hazard rate reduction, for chronic mortality effects, and a range in possible lag times (0 or 40 years lag), as explained in Chapter 2.

Table 3.106: Annual costs and benefits of implementing Measure J in the UK (£millions)[a]

Annual PV of Costs	Annual PV of Benefits	Annual NPV
196	17 – 48	(179) – (148)

[a] Numbers in brackets represent negative values.

243. The results in Table 3.106 above illustrate that the benefits of Measure J are lower than the costs. It should be noted however, that the costs are likely to be an overestimate, as the fuel benefit is not considered.

244. To improve the cost-benefit calculation of Measure J, it would be necessary to further investigate the fuel efficiency of the 'low NO_X' boilers relative to an average minimum standard boiler, in order to capture any fuel savings, the consequent gains in operating costs as well as the social benefits of reduced carbon emissions.

3.3.3 Measure K: SCR on power stations, iron & steel plants and petrol refineries

245. Measure K assumes that coal and gas-fired power stations with 300MW input range reduce their NO_X emissions by Selective Catalytic Reduction (SCR). Under Measure K, iron and steel plants and oil refineries would also adopt SCR. This proposal includes the fitment of SCR on all plants choosing the ELV approach to implementing LCPD in 2010, 6 years ahead of the Large Combustion Plant Directive (LCPD) requirements. Those who chose the cap and trade approach (the NERP approach) will potentially have separate arrangements for installing NOx abatement technologies. The current IGCB analysis has been carried out at relatively high level, and on the current knowledge about the final implementation route on LCPD. A number of additional plants might opt-out of the Directive and choose the allowable derogation, rather than fit abatement equipment from 2010 (and if this is allowed, a change in regulations will be eminent). This possibility has not been considered as part of the current assessment. Furthermore, the possibility of some sectors operating under a national plan approach may lead to a situation where only a few plants choose to install SCR and trade surplus allowances to those who do not. This means that those plants which may have opted for ELV may rather choose to join the NERP in order to trade their surpluses.

246. SCR on coal-fired power stations is required under the LCPD from 2016 for all the plants that chose to opt-in and adopt the ELV approach. Hence, for coal-fired power stations Measure K just brings the introduction date of the LCPD requirements forward for those plants which intend to invest in such equipment. Measure K can therefore be split into two separate measures:

- **Measure K1:** Bringing forward to 2010 the implementation of SCR on coal-fired power stations with a generating capacity greater than or equal to 300MW. This technology is required under the obligations of the Large Combustion Plant Directive (LCPD), by 2016. Hence, in 2016, Measure K1 reverts to the baseline and is considered a short term measure and the cost-benefit analysis only considers the six years between 2010 and 2015. This measure has been updated to reflect those opting into the national plan (or instead opting for limited life derogation), following its submission to the European Commission in February 2006[31]. This measure is assumed to apply across the UK.
- **Measure K2:** Requiring SCR technology on gas-fired power stations, iron and steel plants and petrol refineries. The date of implementation of this measure is 2010. As SCR on these plants are not in the baseline, and are additional measures, Measure K2 is assumed to be a long term measure leading to a sustained pollution reduction. Hence, the cost and benefits are assessed over the period 2010-2109. This measure is assumed to apply across the UK and the rest of Europe.

Benefits of Measure K1

247. The amount of emissions (tonnes) that are saved in 2010, 2015 and 2020 by the early implementation of SCR of coal fired power stations is illustrated in Table 3.107 below. These emission figures have now been refined to reflect the opt out of plants from LCPD requirements and those opting in to the national plan (previous emission figures

[31] The Final National Plan is available at http://www.defra.gov.uk/environment/airquality/eu-int/eu-directives/lcpd/pdf/lcpd_nationalplan.pdf.

did not attempt to capture the impacts from potential opt outs as this information was not known at the time). The modelling does not include an estimate the level of opt-outs in 2016 if such an option were available if implementation were brought forward.

Table 3.107: Change in emissions by implementing Measure K1

Country	Pollutant	Emissions Saved (tonnes)		
		2010	2015	2020
UK	NO_x	172,285	145,876	0

248. Measure K1 has been considered on an emissions-only basis: in order to calculate the benefits of the above reductions in emissions, the damage cost methodology has been used, as described in Chapter 2. The relevant damage cost for each year has been applied to the emission estimates; it is assumed that the 2010 emissions reductions apply between 2010 and 2014, the 2015 emissions reductions apply in 2015.

249. Based on the damage costs analysis, it is possible to estimate the detailed health impacts of a unit reduction in NO_X emissions. Table 3.108 illustrates the health impacts generated by the emission reductions of Measure K1. The introduction of SCR equipment also decreases fuel efficiency and therefore has a carbon penalty; this is also shown in Table 3.108.

Table 3.108: Quantified impacts of implementing Measure K1[a]

PM life years saved ('000s) – 6% (2010 – 2015)	PM – RHA (p.a.)	PM – CHA (p.a.)	Carbon ('000s tonnes p.a.) (2010)
41 – 45	119	119	(148)

[a] at a presented in the table in brackets represents a negative impact – for ozone impacts this reflects the increase in population weighted ozone concentrations presented in the previous table.

250. Applying the damage cost methodology also provides monetary estimates of the benefits. The annual present value in 2005 of the range of benefits is shown in Table 3.109 below.

Table 3.109: Annual present value of impacts of implementing Measure K1 (£millions)[a]

PM life years saved – 6%	PM – RHA	PM – CHA	Carbon
111 – 162	0.2 – 1.0	0.2 – 1.0	(12)

[a] Numbers in brackets represent negative values.

Benefits of Measure K2

251. For Measure K2 (SCR on gas-fired power stations, iron and steel plants and oil refineries) detailed concentration mapping was undertaken. Table 3.110 below shows the resultant population weighted concentrations for each country in 2010, 2015 and 2020 relative to the baseline.

Table 3.110: Change in concentrations by implementing Measure K2 for the UK disaggregated by country

Country	Pollutant	Concentration changes relative to baseline ($\mu g.m^{-3}$)[a]		
		2010	2015	2020
England	PM_{10}	(0.283)	(0.282)	(0.104)
	NO_2	(1.081)	(1.047)	(0.395)
	Ozone	0.163 – 1.041	0.167 – 1.003	0.064 – 0.389
Northern Ireland	PM_{10}	(0.126)	(0.125)	(0.046)
	NO_2	(0.667)	(0.633)	(0.222)
	Ozone	0.084 – 0.443	0.071 – 0.417	0.020 – 0.158
Scotland	PM_{10}	(0.131)	(0.131)	(0.049)
	NO_2	(0.596)	(0.581)	(0.242)
	Ozone	0.102 – 0.649	0.123 – 0.614	0.046 – 0.222
Wales	PM_{10}	(0.221)	(0.219)	(0.081)
	NO_2	(1.090)	(1.102)	(0.449)
	Ozone	0.215 – 1.023	0.258 – 0.996	0.100 – 0.378
UK	PM10	(0.194)	(0.193)	(0.072)
	NO_2	(1.029)	(0.998)	(0.380)
	Ozone	0.158 – 0.989	0.165 – 0.953	0.063 – 0.367

[a] Ozone concentration changes shown as a range incorporating results assuming both a zero threshold and a 50ppb threshold. PM_{10} concentrations are presented in ($\mu g.m^{-3}$, gravimetric).

252. As Measure K2 is assumed to be a long term measure the 2020 concentrations are assumed to persist from 2010 to 2109 and the benefits are calculated on that basis. The quantified health and non-health benefits for Measures K2 have then been calculated from the resulting concentrations using the methodology described in Chapter 2.

253. The use of SCR to reduce NO_X, however, decreases the fuel efficiency of plants and hence increases the amount of carbon emitted. The amount of extra carbon emitted is included in Table 3.111 below, along with the health impacts.

Table 3.111: Quantified impacts of implementing Measure K2[a]

PM life years saved ('000s) – 6% (2010 – 2015)	PM – RHA (2010 p.a.)	PM – CHA (2010 p.a.)	Ozone mortality (2010 p.a.)	Ozone RHA (2010 p.a.)	Carbon ('000s tonnes p.a.) (2010)
152 – 289	25	25	(127) – (22)	(147) – (25)	(155)

[a] at a presented in the table in brackets represents a negative impact – for ozone impacts this reflects the increase in population weighted ozone concentrations presented in the previous table.

254. These benefits have then been monetised using the methodology described in Chapter 2, to generate a Present Value (PV) in 2005 prices of the different impacts. The monetary values can be seen in Table 3.112 below. These monetised impacts now also include the impacts on crop yields and damage to materials avoided due to the reduction in concentrations.

Table 3.112: Annual present value of impacts of implementing Measure K2 (£millions)[a]

PM life years saved – 6%	PM – RHA	PM – CHA	Ozone Mortality	Ozone RHA	Carbon	Crops	Buildings & materials
64 – 151	0.12 – 0.5	0.12 – 0.5	(2) – (0.10)	(3) – (0.11)	(16)	(1)	(1)

[a] Numbers in brackets represent negative values.

Costs of Measure K

255. The methodology for estimating the costs associated with bringing forward the introduction of SCR to coal-fired power stations (Measure K1) has been refined as new information on the numbers of plants opting into the national plan (or opting out under limited life derogation) is now known,

256. The costs for Measure K1 are presented as a range calculated by two methodologies. The first methodology included the costs of bringing forward investment in SCR by 6 years from 2016 to 2010 for those plants planning to fit SCR under the baseline in 2016. It does not however include the possibility of plants entering or leaving the national plan in 2016, and therefore any potentially impacts on security of energy supply. The second methodology included the costs of methodology 1, but also included the costs to those plants not planning to fit SCR under the baseline (that is those that are expected to opt-out and only operate for a limited lifetime under LCPD regulations). The range therefore reflects the uncertainty as to the amount of SCR investment that those opted out plants will make during their limited life derogation.

257. The identification of coal-fired plants that fall under these two measures, as well as the load factors for power stations are consistent with DTIs UEP12[32] assumptions.

258. The costs used in the cost-benefit calculation include the capital costs of fitting SCR on all the different types of plant, and the additional operating costs (Entec 2003a, RAINS).[33] The capital cost of SCR abatement has also been revised to reflect more recent cost information from industry during the consultation process. To match the timeframe over which the benefits are being analysed, the capital costs of Measure K1 were included in 2010, operating costs were added each year from 2011-2016, and then the capital costs were subtracted in 2016, as they would have been in the baseline at this point.

259. For Measure K2, the capital costs of SCR for the relevant plants were included in 2010, followed by 14 years of operating costs. This cost profile was then repeated every 15 years until 2109 in order to match the cost profile with that of the benefits modelling.

260. The costs for both Measures K1 and K2 were then discounted back to 2005 to calculate the present value (PV) of the costs in 2005 prices, and annualised. The capital costs, operating costs and annualised present value of the costs are illustrated in Table 3.113 below.

Table 3.113: Costs of implementing Measure K in the UK in 2005 prices (£millions)

Measure	Lifetime of Technology (years)	Capital Cost (2005 prices)	Operating Cost (2005 prices)	Annual PV of Costs
K1	6	1,148 – 1,589	101 – 126	118 – 206
K2	15	2,844	94	273

Cost and benefits of Measure K

261. Table 3.114 below presents the annual Net Present Value (NPV) of Measure K, that is the annual benefits minus the annual costs. This is based on a 6% hazard rate reduction, for chronic mortality effects, and a range in possible lag times (0 or 40 years lag), as explained in Chapter 2.

Table 3.114: Annual costs and benefits of implementing Measure K in the UK (£millions)[a]

	Annual PV of Costs	Annual PV of Benefits	Annual NPV
K1	118 – 206	99 – 152	(107) – 34
K2	273	41 – 134	(232) – (139)

[a] Numbers in brackets represent negative values.

[32] 'Updated Energy Projections (UEP12) for the Power Sector', Department of Trade and Industry (2004).

[33] Entec (2003a) 'Revision of Cost Curve for NOX', report prepared for the Department for environment, Food and Rural Affairs. RAINS model: version CP_CLE_Aug04(Nov04).

262. The table above shows that the costs outweigh the benefits of Measure K when the 6% hazard rate is used for the 40 year lag scenario. However for measure K1 the no-lag scenario, the benefits outweigh the costs. The latest statements from COMEAP suggest that, although evidence was limited, the Committee's judgement tends towards a greater proportion of the effect occurring in the years sooner after the pollution reduction rather than later. This would mean that the effect is more likely to be nearer the no lag result.

3.3.4 Measure L – Small combustion plants: 50% reduction in NO_2 and SO_2 emissions

263. Measure L assumes that a hypothetical EU Small Combustion Plant Directive (SCPD), or a revision to the existing IPPC or LCPD Directive, comes into force in 2008. The working assumption (and hence the measure being looked at) is that this would lead to a 50% reduction in SO_2 and NO_X emissions by 2013 from plants that use between 20-50MW. Table 3.115 indicates the sectors from which the NO_X and SO_2 emissions reductions are generated. This data is consistent with the National Atmospheric Emissions Inventory.[34]

Table 3.115: Sector sources from which the 50% reduction in NO_X and SO_2 emissions is achieved for Measure J

SO_2		NO_X	
PUBLIC SERVICES	FUEL OIL	MISCELLANEOUS	NATURAL GAS
AUTOGENERATORS	COAL	PUBLIC SERVICES	FUEL OIL
Other industry (Combustion)	COAL	PUBLIC SERVICES	NATURAL GAS
Other industry (Combustion)	COKE	AUTOGENERATORS	COAL
Other industry (Combustion)	FUEL OIL	Other industry (Combustion)	COAL
Other industry (Combustion)	GAS OIL	Other industry (Combustion)	COKE
		Other industry (Combustion)	FUEL OIL
		Other industry (Combustion)	GAS OIL
		Other industry (Combustion)	NATURAL GAS

264. The 50 per cent reduction in SO_2 emissions are assumed to be reached by the use of low sulphur fuels. The 50 per cent NO_X reductions are assumed to be obtained by combustion modifications. A 100 per cent uptake of the measure is assumed. The lifetime of these NO_X technologies is assumed to be 20 years. However, given the very large number of installations that may potentially be affected, each one using a different type of technology, the current analysis does not consider this level of detail as the analysis is being performed at a relatively high level.

[34] Stedman et al (2006) 'Projections of Air Quality in the UK for Additional Measures Scenarios for the 2006 Review of the Air Quality Strategy', National Atmospheric Emissions Inventory, AEA Technology, National Environmental Technology Centre. Report AEAT/ENV/R/1986.

Benefits of Measure L

265. Detailed concentration mapping of the NO_X emissions, SO_2 emissions, resulting secondary particulate matter concentrations and resulting ozone concentrations was carried out in order to calculate the benefits of this measure (the methodology for the mapping has been described in more detail in Chapter 2 and the AQS review consultation document). Table 3.116 below shows the resultant population weighted concentrations for each country in 2010, 2015 and 2020 relative to the baseline.

Table 3.116: Change in concentrations by implementing Measure L for the UK disaggregated by country.

Country	Pollutant	Concentration changes relative to baseline ($\mu g.m^{-3}$)[a]		
		2010	2015	2020
England	PM_{10}	0.000	(0.038)	(0.031)
	NO_2	0.000	(0.276)	(0.303)
	Ozone	0.000	0.014 – 0.097	0.017 – 0.102
Northern Ireland	PM_{10}	0.000	(0.018)	(0.015)
	NO_2	0.000	(0.089)	(0.096)
	Ozone	0.000	0.005 – 0.020	0.003 – 0.021
Scotland	PM_{10}	0.000	(0.019)	(0.016)
	NO_2	0.000	(0.268)	(0.291)
	Ozone	0.000	0.008 – 0.048	0.009 – 0.048
Wales	PM_{10}	0.000	(0.031)	(0.025)
	NO_2	0.000	(0.236)	(0.278)
	Ozone	0.000	0.013 – 0.065	0.016 – 0.064
UK	PM_{10}	0.000	(0.036)	(0.029)
	NO_2	0.000	(0.268)	(0.295)
	Ozone	0.000	0.013 – 0.089	0.016 – 0.093

[a] Ozone concentration changes shown as a range incorporating results assuming both a zero threshold and a 50ppb threshold. PM_{10} concentrations are presented in ($\mu g.m^{-3}$, gravimetric).

266. Measure L will have a long term impact as once these technologies are adopted they will apply to all plants in the future. Hence, the benefit analysis is calculated on the assumption of a 100 year sustained pollution reduction, both for NO_X and SO_2. Table 3.117 illustrates the health impacts generated by the changes in NO_X concentrations and the changes in SO_2 emissions generated by Measure L.

267. It was not possible to calculate the impact this measure would have on the fuel efficiency of SCPs, hence it was not possible to quantify any potential change in carbon emissions.

Table 3.117: Quantified impacts of implementing Measure L[a]

PM life years saved ('000s) – 6% (2010 – 2109)	PM – RHA (2020 p.a.)	PM – CHA (2020 p.a.)	Ozone mortality (2020 p.a.)	Ozone RHA (2020 p.a.)	SO_2 as gas[b] – Mortality (2020 p.a.)	SO_2 as gas[b] – RHA (2020 p.a.)
62 – 118	11	11	(32) – (5)	(37) – (6)	16	13

[a] Data presented in the table in brackets represents a negative impact – for ozone impacts this reflects the increase in population weighted ozone concentrations presented in the previous table.

[b] This relates to the direct effects of SO_2 as a gas rather than the effects of SO_2 as a precursor of sulphate (the latter is covered under the PM health effects).

268. These benefits have then been monetised using the methodology described in Chapter 2, to generate a Present Value (PV) in 2005 prices of the different impacts and then annualised. The monetary values can be seen in Table 3.118 below. These monetised impacts now also include the impacts on crop yields and damage to materials avoided due to the reduction in concentrations.

Table 3.118: Annual present value of impacts of implementing Measure L (£millions)[a]

PM life years saved – 6%	PM – RHA	PM – CHA	Ozone Mortality	Ozone RHA	SO_2 Mortality	SO_2 RHA	Crops	Buildings & materials
28 – 65	0.04 – 0.18	0.04– 0.18	(0.46) – (0.03)	(1) – (0.02)	0.08 – 0.23	0.05 – 0.23	(1)	1

[a] Numbers in brackets represent negative values.

Costs of Measure L

269. The additional operating costs of using low sulphur fuels have been derived by Entec (2004).[35] They range between £310,000 and £3 million p.a. for each sector being considered. The range reflects the different potential emissions reductions achievable by the different sectors complying with the SO_2 requirements of Measure L. The capital costs of SCPs modifying combustion in order to reduce their NO_X emissions are derived from RAINS (2004).[36] These costs range between £400,000 and £61 million for each sector and again the range reflects the difference in abatement costs across sectors. No change in operating costs from fitting these technologies is assumed. The lifetime of the technology is assumed to be 20 years.

[35] Entec (2004) 'Revision of the Cost Curve for SO2', report prepared for the Department for Environment, Food and Rural Affairs

[36] RAINS model: version CP_CLE_Aug04(Nov04).

270. It was not possible to calculate any potential change in energy efficiency due to Measure L (especially given that the plants affected are varied in terms of technologies, fuel mix, flue arrangements etc). Any change in the amount of fuel consumed and the costs of these fuel penalties or savings have not been quantified. Hence, no change in operating costs from fitting these technologies is assumed.

271. The costs do not include any impact on international competitiveness that may arise from increasing the costs of particular sectors.

272. Measure L is assumed to have a lasting impact on concentrations, hence the benefits are calculated over a 100 year period. To match the costs to this benefit profile, annual costs associated with the SO_2 reduction have been applied to 2109. The capital costs associated with the NO_X reduction have been re-applied every 20 years till 2109. This stream of costs was then discounted to obtain the present value of the costs in 2005 prices, and then annualised to be comparable with the annual benefits. The capital costs and the annual present value of the costs are illustrated in Table 3.119.

Table 3.119: Costs of implementing Measure L in the UK in 2005 prices (£millions)

Lifetime of Technology (years)	Capital Cost (2005 prices)	Operating Cost (2005 prices)	Annual PV of Costs
20	96	5	9

Cost and benefits of Measure L

273. Table 3.120 below presents the annual Net Present Value (NPV) of Measure L, that is the annual benefits minus the annual costs. This is based on a 6% hazard rate reduction, for chronic mortality effects, and a range in possible lag times (0 or 40 years lag), as explained in Chapter 2.

Table 3.120: Annual costs and benefits of implementing Measure L in the UK (£millions)[a]

Annual PV of Costs	Annual PV of Benefits	Annual NPV
9	27 – 66	18 – 57

[a] Numbers in brackets represent negative values.

274. The table above shows that the benefits outweigh the costs of Measure L based on the recommended 6% hazard rate reduction for both the lag and the no-lag scenario.

275. The cost-benefit calculation of Measure L, could be improved by further investigation of the effect the measure has on the fuel efficiency of SCPs, the differences in the plant configuration, the fuel mix and technology differences and the technological requirements for each type of plant. It would then be possible to capture any fuel savings/costs, the consequent change in operating costs as well as the social impact of a change in carbon emissions.

3.3.5 Measure M – Reducing national VOC emissions by 10%

276. Measure M assumes that UK Volatile Organic Compound (VOCs) emissions are reduced by 10 per cent from the baseline. VOCs are a precursor for ozone, hence a reduction in VOC emissions would reduce ozone and the consequent health impacts. This measure is assumed to apply in the UK only.

277. The measures that would achieve this reduction would be implemented in 2010. To achieve this 10 per cent reduction it was assumed that the following abatement technologies are implemented:

- Petrol stations Stage II controls > 3,000m^3 throughput
- Chemical and man made fibre production – thermal oxidation (TO)
- Chemical and man made fibre production – road tanker vapour recovery
- Chemical and man made fibre production – storage tank replacement Programme (TRP)
- Chemical and man made fibre production – leak detection & repair (LDAR)
- Chemical and man made fibre production – second stage vapour recovery unit (VRU)
- Chemical and man made fibre production – cryogenic condensation (CC)
- Offshore loading of crude oil – modification to shuttle tankers (MST)
- Offshore loading of crude oil – modification to floating production, storage & off-take vessels (MFPSO)
- Offshore loading of crude oil – vapour recovery unit (from ship loading) (VRU)

Benefits of Measure M

278. The benefits of reducing VOC emissions are generated from the consequent reduction in ozone emissions. The change in ozone concentrations were modelled using the Ozone Source Receptor Model developed by Netcen.[37] The benefits generated from reducing ozone emissions are reductions in acute mortality effects, respiratory hospital admission and crop and materials damage. As explained in Chapter 2, the calculation of the health benefits from ozone assume different thresholds, hence the quantified results are illustrated with a range.

[37] Hayman et al (2005), 'Modelling of Tropospheric Ozone', AEA Technology, National Environmental Technology Centre. Report AEAT/ENV/R/1958.

279. Detailed concentration mapping of the ozone concentrations was carried out in order to calculate the benefits of this measure (the methodology for the mapping has been described in more detail in Chapter 2 and the AQS review consultation document). Table 3.121 below shows the resultant population weighted concentrations for each country in 2010, 2015 and 2020 relative to the baseline.

Table 3.121: Change in concentrations by implementing Measure M for the UK disaggregated by country.

Country	Pollutant	Concentration changes relative to baseline ($\mu g.m^{-3}$)[a]		
		2010	2015	2020
England	Ozone	(0.023) – (0.006)	(0.027) –(0.009)	(0.029) – (0.011)
Northern Ireland	Ozone	(0.020) – (0.010)	(0.023) –(0.012)	(0.023) – (0.014)
Scotland	Ozone	(0.025) – (0.008)	(0.029) – (0.010)	(0.031) – (0.011)
Wales	Ozone	(0.025) – (0.010)	(0.030) – (0.014)	(0.031) – (0.017)
UK	Ozone	(0.024) –(0.007)	(0.027) – (0.009)	(0.029) – (0.011)

[a] Ozone concentration changes shown as a range incorporating results assuming both a zero threshold and a 50ppb threshold. PM_{10} concentrations are presented in ($\mu g.m^{-3}$, gravimetric).

280. Measure M is assumed to lead to a sustained change in ozone concentrations, as once the abatement technologies are fitted they will be required into the future for existing and new plants and processes. The benefits are therefore calculated over the period 2010 – 2109. Table 3.122 illustrates the quantified health impacts.

Table 3.122: Quantified impacts of implementing Measure M

Ozone mortality (2020 p.a.)	Ozone RHA (2020 p.a.)
4 – 10	4 – 12

281. These benefits have then been monetised using the methodology described in Chapter 2, to generate a Present Value (PV) in 2005 prices of the different impacts. The monetary values can be seen in Table 3.123 below. These monetised impacts include the impacts on crop yields and damage to materials avoided due to the reduction in concentrations.

Table 3.123: Annual present value of impacts of implementing Measure M (£millions)

Ozone Mortality	Ozone RHA	Crops	Buildings & materials
0.02 – 0.14	0.02 – 0.20	0.25	0.04

Costs of Measure M

282. The capital and operating costs for each of the VOC abatement techniques are listed in Table 3.124 below. The source of the costs for all the sectors apart from the petrol stations is Entec (2003b).[38] The costs for Petrol Vapour Recovery Stage II controls are derived from the PVRII RIA (2005).[39]

Table 3.124: Costs of implementing Measure M (£millions)

Sector	Source	Abatement Technology	Operating Life (years)	Capital Cost (£m)	Operating Cost (£m)	Annualised PV of costs (2006-2105)
On and Off-shore Loading	On and off-shore loading crude oil	VRU	15	1,682	68	177
	On and off-shore loading crude oil	MFPSO	15	282	–	20
	On and off-shore loading crude oil	MST	15	305	–	22
Organic chemical industry	Chemicals & man-made fibres	TO	15	69	3	7
	Chemicals & man-made fibres	LDAR	20	–	3	2
	Chemicals & man-made fibres	SSVRU	15	27	1	3
	Chemicals & man-made fibres	TRP	20	55	–	3
	Chemicals & man-made fibres	RTVRU	15	3	0.1	0.4
	Chemicals & man-made fibres	CC	20	9	1	1
Petrol stations	Petrol stations, vehicle refuelling	PVR Stage II	15	167	2	13
Total (£millions)				2,599	77	249

283. The costs for PVR Stage II controls assume an economic lifetime of 15 years for the equipment. Shorter lifetimes have also been considered as sensitivity analysis in Chapter 5. The 15 year lifetime used in the above costs results in lower total annualised costs, compared to using a shorter lifetime. However, 15 years was considered as the central analysis in this chapter to be consistent with the methodology used to calculate the emission reductions.

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[38] Entec (2003b) 'Revision of the Cost Curve for VOC', report prepared for the Department for Environment, Food and Rural Affairs

[39] Final Regulatory Impact Assessment on Petrol Vapour Recovery Stage II Controls (PVRII)', Defra, (2005c). Available at http://www.defra.gov.uk/corporate/consult/pvr-stage2/pvrstage2-ria.pdf

Costs and benefits of Measure M

284. Table 3.125 below presents the annual Net Present Value (NPV) of Measure M, that is the annual benefits minus the annual costs. The results show that costs significantly outweigh the benefits for this measure.

Table 3.125: Annual costs and benefits of implementing Measure M in the UK (£millions)[a]

Annual PV of Costs	Annual PV of Benefits	Annual NPV
249	0.33 – 0.63	(249) – (248)

[a] Numbers in brackets represent negative values.

3.3.6 Measure N – Reducing emissions from shipping.

285. Measure N is aimed at controlling emissions of nitrogen oxides and sulphur dioxide . It is based on an assumption that all ships that weigh more than 100 tonnes would start using fuel with reduced sulphur content (it assumes a move in waters surrounding the UK to 1% sulphur fuel from the current standard of 1.5% sulphur fuel[40]) and reduce their NOx emissions by 25%. This measure forms part of the proposed package of measures in the Air Quality Strategy and part of the new combined measure R. It should, however, be noted that this measure represents only one of several possible courses of action that the International Maritime Organisation (IMO) might choose to pursue and does not necessarily represent the UK's preferred option.

286. The assumption is that old and new vessels will be required to use cleaner fuel. Only new ships however will have to reduce their NOx emissions by 25%. The introduction of new ships to the fleet is assumed to be 1/30th of the fleet a year. The assumption is that this measure would be applicable from 2010

287. Costs and benefits for this measure have been assessed on a UK basis as recommended by the Green Book.[41] For benefits, this includes benefits to the UK from both UK and foreign ships in UK waters (benefits to other countries from UK ships have not therefore been included). Costs have been calculated for the UK fleet. While it is clear there are benefits and costs outside the UK it is not feasible to carry out a 'global' cost-benefit analysis given the uncertainties and complexities involved.

Benefits of Measure N

288. Since Measure N is assumed to be implemented at an international level, the UK will benefit not only from improvements in the UK fleet but also from reductions in emissions from those elements of the global fleet that might affect air quality in the UK. The modelling of the benefits have therefore included these benefits. It does not, however, include additional benefits that would accrue to countries outside the UK as a result of this measure. The proportion of UK secondary particulate matter concentration derived from maritime sources (34% of sulphate and 23% of nitrate in

[40] The assumption of the base line figure of 1.5% sulphur fuel is derived from the current Sulphur Emission Control Area (SECA) system that is applicable in the majority of the waters surrounding the UK. However the real average sulphur content is likely to be higher as the current global limit of 4.5% sulphur applies in wider waters.

[41] 'Green Book; Appraisal and Evaluation in Central Government', HM Treasury (2003). Available at http://greenbook.treasury.gov.uk

2010) has been reduced in line with the expected decline in concentrations associated with the reduction in maritime emissions.

289. Table 3.126 below shows the resultant population weighted concentrations of each pollutant for each country in 2010, 2015 and 2020 relative to the baseline.

Table 3.126: Change in concentrations by implementing Measure N for the UK disaggregated by country

Country	Pollutant	Concentration changes relative to baseline ($\mu g.m^{-3}$)a		
		2010	2015	2020
England	PM_{10}	(0.206)	(0.257)	(0.290)
	NO_2	(0.014)	(0.082)	(0.143)
Northern Ireland	PM_{10}	(0.115)	(0.135)	(0.148)
	NO_2	(0.009)	(0.052)	(0.087)
Scotland	PM_{10}	(0.115)	(0.137)	(0.151)
	NO_2	(0.008)	(0.045)	(0.070)
Wales	PM_{10}	(0.178)	(0.216)	(0.240)
	NO_2	(0.012)	(0.065)	(0.123)
UK	PM_{10}	(0.194)	(0.241)	(0.272)
	NO_2	(0.013)	(0.077)	(0.127)

[a] Ozone concentration changes shown as a range incorporating results assuming both a zero threshold and a 50ppb threshold. PM_{10} concentrations are presented in ($\mu g.m^{-3}$, gravimetric).

290. Measure N is assumed to lead to a sustained change in concentrations. The benefits are therefore calculated over the period 2010 – 2109. Table 3.127 illustrates the quantified health impacts.

Table 3.127: Quantified impacts of implementing Measure N[a]

PM life years saved ('000s) – 6% (2010 – 2109)	PM – RHA (2020 p.a.)	PM – CHA (2020 p.a.)	SO_2 as gas[b] – Mortality (2020 p.a.)	SO_2 as gas[b] – RHA (2020 p.a.)
576 – 1,100	95	96	1.4	1.1

[a] Data presented in the table in brackets represents a negative impact – for ozone impacts this reflects the increase in population weighted ozone concentrations presented in the previous table.

[b] This relates to the direct effects of SO_2 as a gas rather than the effects of SO_2 as a precursor of sulphate (the latter is covered under the PM health effects).

291. These benefits have then been monetised using the methodology described in Chapter 2, to generate a Present Value (PV) in 2005 prices of the different impacts. The monetary values can be seen in Table 3.128 below.

Table 3.128: Annual present value of impacts of implementing Measure N (£millions)[a]

PM life years saved – 6%	PM – RHA	PM – CHA	SO_2 as gas – Mortality	SO_2 as gas – RHA	Buildings & materials
244 – 573	1 – 2	1 – 2	0.002 – 0.005	0.05 – 0.23	0.09

[a] Numbers in brackets represent negative values.

Costs of Measure N

292. The costs of Measure N only include those costs due to the impact on the UK fleet. To achieve the reductions in NO_X emissions, two solutions have been considered: advanced internal engine modifications (IEM) and selective catalytic reduction. The advanced IEM solution is more consistent with the definition of Measure N since it is estimated to achieve around a 30% improvement in NO_X emissions; the SCR solution would achieve emissions reductions well in excess of those defined in the measure (up to 90%). The costs for advanced IEM are therefore used in the central analysis presented here; the SCR costs are presented in Chapter 5 for comparison.

293. Benefits for Measure N have been estimated to 2109. For consistency the costs have therefore also been considered over the period 2010 to 2109. The assumed lifetime of the advanced IEM technology is 25 years; the capital costs have therefore been replicated every 25 years over the period 2010 to 2109.

294. The SO_2 emissions are assumed to be achieved by switching from 1.5% to 1% sulphur fuel from 2010. The associated operating costs have been extended to 2109.

295. Table 3.129 shows the capital, operating and total annualised costs associated with Measure N.

Table 3.129: Costs of implementing Measure N in the UK in 2005 prices (£millions)

Lifetime of Technology (years)	Capital Cost (2005 prices)	Operating Cost (2005 prices)	Annual PV of Costs
20	0.5	0.8	1

Costs and benefits of Measure N

296. Table 3.130 below presents the annual Net Present Value (NPV) of Measure N, that is the annual benefits minus the annual costs. This is based on a 6% hazard rate reduction, for chronic mortality effects, and a range in possible lag times (0 or 40 years lag), as explained in Chapter 2.

Table 3.130: Annual costs and benefits of implementing Measure N in the UK (£millions)[a]

Annual PV of Costs	Annual PV of Benefits	Annual NPV
1	246 – 577	245 – 576

[a] Numbers in brackets represent negative values.

297. The table above shows that the benefits outweigh the costs of Measure N based on the recommended 6% hazard rate reduction for both the lag and the no-lag scenario. Further sensitivity analysis of the impacts on the NPV of this measure when duration is changed is presented in Chapter 5.

3.4 Costs and benefits of combined measures

298. This section presents the results from the combined measures i.e. measures that incorporate a number of the different measures assessed in the previous two sections.

299. The measures presented in this section are:

- **Measure O:** a combination of Measure C (incentivising early uptake of Euro 5/V/VI standards) and Measure E (incentives to increase the uptake of LEVs);
- **Measure P:** a combination of Measure C (incentivising early uptake of Euro 5/V/VI standards) and Measure L (Small Combustion Plant measure); and
- **Measure Q:** a combination of Measure C (incentivising early uptake of Euro 5/V/VI standards), Measure E (increased uptake of LEVs) and Measure L (Small Combustion Plant measure); and
- **Measure R:** a new combined measure comprising the measures identified for further consideration in the new Air Quality Strategy, This is a combination of Measure C2 (early uptake of Euro 5/6/V/VI standards), Measure E (increased uptake of LEVs) and Measure N (shipping measure).

300. The combined emissions reductions from the relevant measures have been used as inputs into separate concentration modelling for each of these combined measures. These results have then been used to estimate the health and non-health impacts, which have been quantified and monetised according the methodology set out in Chapter 2.

301. The costs of the combined measures are assumed to be additive i.e. the sum the costs of the individual measures included in each combined measure.

Benefits of combined Measures O, P, Q and R

302. Detailed concentration mapping of the NO_X and PM_{10} emissions, resulting secondary particulate emissions, and resulting ozone concentrations was carried out in order to calculate the benefits of these measures (the methodology for the mapping has been described in more detail in Chapter 2). The change in concentrations form implementing each of the combined measures is shown in Tables 3.131 – 3.134 below.

Table 3.131: Change in concentrations by implementing Measure O for the UK disaggregated by country.

Country	Pollutant	Concentration changes relative to baseline ($\mu g.m^{-3}$)[a]		
		2010	2015	2020
England	PM_{10}	(0.159)	(0.469)	(0.665)
	NO_2	(0.219)	(0.946)	(1.553)
	Ozone	0.019 – 0.150	0.077 – 0.673	0.110 – 1.056
Northern Ireland	PM_{10}	(0.065)	(0.194)	(0.276)
	NO_2	(0.129)	(0.553)	(0.823)
	Ozone	0.007 – 0.046	0.019 – 0.148	(0.016) – 0.155
Scotland	PM_{10}	(0.104)	(0.301)	(0.426)
	NO_2	(0.178)	(0.774)	(1.210)
	Ozone	0.009 – 0.076	0.038 – 0.297	0.033 – 0.378
Wales	PM_{10}	(0.091)	(0.274)	(0.389)
	NO_2	(0.163)	(0.758)	(1.238)
	Ozone	0.012 – 0.088	0.058 – 0.389	0.053 – 0.539
UK	PM_{10}	(0.148)	(0.438)	(0.620)
	NO_2	(0.211)	(0.911)	(1.487)
	Ozone	0.018 – 0.138	0.071 – 0.612	0.097 – 0.946

[a] Ozone concentration changes shown as a range incorporating results assuming both a zero threshold and a 50ppb threshold. PM_{10} concentrations are presented in ($\mu g.m^{-3}$, gravimetric).

Table 3.132: Change in concentrations by implementing Measure P for the UK disaggregated by country.

Country	Pollutant	Concentration changes relative to baseline ($\mu g.m^{-3}$)[a]		
		2010	2015	2020
England	PM_{10}	(0.152)	(0.491)	(0.685)
	NO_2	(0.191)	(1.131)	(1.664)
	Ozone	0.017 – 0.134	0.084 – 0.714	0.108 – 1.046
Northern Ireland	PM_{10}	(0.062)	(0.206)	(0.287)
	NO_2	(0.112)	(0.576)	(0.794)
	Ozone	0.006 – 0.041	0.020 – 0.151	(0.019) – 0.142
Scotland	PM_{10}	(0.101)	(0.314)	(0.438)
	NO_2	(0.153)	(0.965)	(1.339)
	Ozone	0.007 – 0.067	0.041 – 0.316	0.031 – 0.368
Wales	PM_{10}	(0.086)	(0.295)	(0.409)
	NO2	(0.140)	(0.933)	(1.343)
	Ozone	0.010 – 0.078	0.067 – 0.421	0.057 – 0.542
UK	PM_{10}	(0.142)	(0.458)	(0.638)
	NO_2	(0.183)	(1.092)	(1.596)
	Ozone	0.016 – 0.123	0.077 – 0.649	0.095 – 0.937

[a] Ozone concentration changes shown as a range incorporating results assuming both a zero threshold and a 50ppb threshold. PM_{10} concentrations are presented in ($\mu g.m^{-3}$, gravimetric).

Table 3.133: Change in concentrations by implementing Measure Q for the UK disaggregated by country.

Country	Pollutant	Concentration changes relative to baseline ($\mu g.m^{-3}$)[a]		
		2010	2015	2020
England	PM_{10}	(0.159)	(0.496)	(0.696)
	NO_2	(0.219)	(1.230)	(1.873)
	Ozone	0.019 – 0.150	0.092 – 0.769	0.125 – 1.155
Northern Ireland	PM_{10}	(0.065)	(0.207)	(0.291)
	NO_2	(0.129)	(0.648)	(0.921)
	Ozone	0.007 – 0.046	0.021 – 0.169	(0.016) – 0.173
Scotland	PM_{10}	(0.104)	(0.314)	(0.441)
	NO2	(0.178)	(1.047)	(1.507)
	Ozone	0.009 – 0.076	0.045 – 0.344	0.038 – 0.420
Wales	PM_{10}	(0.091)	(0.296)	(0.415)
	NO_2	(0.163)	(1.023)	(1.508)
	Ozone	0.012 – 0.088	0.072 – 0.452	0.067 – 0.599
UK	PM_{10}	(0.148)	(0.462)	(0.649)
	NO_2	(0.211)	(1.188)	(1.797)
	Ozone	0.018 – 0.138	0.085 – 0.700	0.111 – 1.036

[a] Ozone concentration changes shown as a range incorporating results assuming both a zero threshold and a 50ppb threshold. PM_{10} concentrations are presented in ($\mu g.m^{-3}$, gravimetric).

Table 3.134: Change in concentrations by implementing Measure R for the UK disaggregated by country.

Country	Pollutant	Concentration changes relative to baseline ($\mu g.m^{-3}$)[a]		
		2010	2015	2020
England	PM_{10}	(0.306)	(0.773)	(0.992)
	NO_2	(0.281)	(1.354)	(2.332)
	Ozone	0.000 – 0.117	0.013 – 0.636	0.003 – 1.023
Northern Ireland	PM_{10}	(0.159)	(0.325)	(0.443)
	NO_2	(0.171)	(0.785)	(1.150)
	Ozone	(0.011) – 0.004	(0.039) – 0.005	(0.163) – (0.146)
Scotland	PM_{10}	(0.180)	(0.422)	(0.592)
	NO_2	(0.228)	(1.083)	(1.792)
	Ozone	(0.010) – 0.045	(0.016) – 0.220	(0.093) – 0.200
Wales	PM_{10}	(0.237)	(0.487)	(0.665)
	NO_2	(0.213)	(1.133)	(1.864)
	Ozone	(0.016) – 0.052	(0.034) – 0.317	(0.136) – 0.362
UK	PM_{10}	(0.288)	(0.661)	(0.926)
	NO_2	(0.270)	(1.304)	(2.228)
	Ozone	(0.002) – 0.124	0.009 – 0.670	(0.017) – 1.053

[a] Ozone concentration changes shown as a range incorporating results assuming both a zero threshold and a 50ppb threshold. PM_{10} concentrations are presented in ($\mu g.m^{-3}$, gravimetric).

303. The quantified health and non-health benefits for each of the combined measures have been calculated from the concentrations presented above using the methodology described in Chapter 2 and the specific assumptions set out for component Measures earlier in this chapter. Table 3.135 illustrates the health impacts generated by the above changes in concentrations. To put these into context, the health impact from the measures already agreed in the baseline is a gain of 6.4 to 12.2 million life years (see section 2.8.2.2 in Chapter 2). Measure R, for example, gives a further gain of 2.0 to 3.8 million life years.

Table 3.135: Quantified impacts of implementing combined Measures O, P, Q & R[a]

	PM life years saved ('000s) – 6% (2010 – 2109)	PM – RHA (2020 p.a.)	PM – CHA (2020 p.a.)	Ozone mortality (2020 p.a.)	Ozone RHA (2020 p.a.)	SO2 as gasb – Mortality (2020 p.a.)	SO_2 as gas[b] – RHA (2020 p.a.)	Carbon ('000s tonnes p.a.) (2020)
O	1,389 – 2,586	217	218	(327) – (33)	(378) – (39)	–	–	442
P	1,428 – 2,660	218	218	(324) – (33)	(375) – (38)	16	13	(552)
Q	1,450 – 2,704	224	224	(359) – (38)	(414) – (14)	16	13	442
R	2,020 – 3,805	325	326	(364) – 6	(421) – 7	1.4	1.1	378

[a] Data presented in the table in brackets represents a negative impact – for ozone impacts this reflects the increase in population weighted ozone concentrations presented in the previous table.

[b] This relates to the direct effects of SO_2 as a gas rather than the effects of SO_2 as a precursor of sulphate (the latter is covered under the PM health effects).

304. These benefits have then been monetised using the methodology described in Chapter 2 and discounted to generate a Present Value (PV) in 2005 prices of the different impacts. This present value has then been annualised. The monetary values for each combined measure can be seen in Table 3.136 below. These monetised impacts include the impacts on crop yields and damage to buildings and materials avoided due to the reduction in concentrations.

Table 3.136: Annual present value of impacts of implementing combined Measures O, P, Q and R (£millions)[a]

	PM life years saved – 6%	PM – RHA	PM – CHA	Ozone Mortality	Ozone RHA	SO_2 as gas Mortality	SO_2 as gas RHA	Carbon	Crops	Buildings & materials
O	627 – 1,396	1 – 3	1 – 3	(5) – (0.17)	(6) – (0.13)	–	–	42	2	2
P	644 – 1,458	1 – 3	1 – 3	(5) – (0.17)	(6) – (0.13)	0.08 – 0.23	0.05 – 0.23	(50)	1	3
Q	653 – 1,480	1 – 3	1 – 3	(5) – (0.19)	(6) – (0.15)	0.08 – 0.23	0.05 – 0.23	42	1	3
R	886 – 2,039	1 - 5	1 - 5	(5) – 0.02	(5) – 0.02	0.002 – 0.005	0.05 – 0.23	36	2	2

[a] Numbers in brackets represent negative values.

Costs of combined Measures O, P, Q and R

305. The total costs of the implementation of each combined measure are presented in Table 3.137 below, representing the sum of the costs of each component measure. The total costs include the annualised technology costs, the resource costs of the measure as well as the welfare impacts due to the rebound effect, which are discounted using the appropriate standard HM Treasury Green Book discount rate and annualised over the period between the implementation date for each vehicle type and 2109. For combined Measures P and Q, which include Measure L, capital costs and operating costs are also included, which have been annualised over a period of 100 years to 2109.[42]

Table 3.137: Costs of implementing the combined Measures O, P, Q and R in the UK in 2005 prices (£millions)[a]

	Annualised Technology Costs	Annualised Resource cost of extra fuel consumed	Annualised Welfare impact due to rebound effect	Capital Cost	Operating Cost	Annual PV of Costs
O	571 – 579	(95)	(6)	–	–	470 – 478
P	276 – 284	132	1	96	5	418 – 426
Q	571 – 579	(95)	(6)	96	5	479 – 487
R	966 - 972	(83) – (82)	(6)	0.5	0.8	878 – 885

Cost and benefits of the combined measures

306. Table 3.138 below presents the annual Net Present Value (NPV) of the combined measures (Measures O, P, Q and R), that is the annual benefits minus the annual costs.

[42] Capital costs have been re-applied every 20 years until 2109.

Table 3.138: Annual costs and benefits of implementing combined Measures O, P, Q and R in the UK (£millions)[a]

	Annual PV of Costs	Annual PV of Benefits	Annual NPV
O	470 - 478	664 – 1,448	186 – 978
P	418 – 426	589 – 1,418	163 – 1,000
Q	479 – 487	690 – 1,532	203 – 1,053
R	878 – 885	918 – 2,089	33 – 1,211

[a] Numbers in brackets represent negative values.

307. The table above shows that the annualised benefits outweigh the annualised costs for each of the combined options at the recommended 6% hazard rate.

Chapter 4: Non-monetary assessments of additional measures

KEY UPDATES TO THE CHAPTER

This chapter has been updated to reflect the results of the various non-monetary assessments of new or updated measures. Changes to measures have been set out at the start of Chapter 3. In brief these are:

- A new **Measure A2 (Euro revised)** which has been modelled to reflect recent European Parliament proposals for emissions standards
- A new **Measure C2 (Early Euro revised)** which incentivises the early uptake of the Euro 5/V emissions standards modelled in the new Measure A2 above, and forms part of the new combined scenario (Measure R).
- A revised **Measure H (Retrofit)** reflecting better information on cost assumptions.
- An updated **Measure K1 (Early LCP)** to reflect recent information about opt outs to the UK's national plan for LCPD.
- A new combined measure **(Measure R)** reflecting the proposed package of measures set out in the new Air Quality Strategy. This replaces the previous combined measures (Measures O, P and Q) although these have been presented for completeness.

The series of non-monetary assessments presented in this chapter now include two further impacts: the impacts of air quality on quality of life and physical activity. Further development of these areas, within the assessment framework, has been identified and will be taken forward as part of the future work programme for IGCB as set out in section 6.3 of Chapter 6.

4.1 What's included in the non-monetary assessments?

1. As discussed in Chapter 2, there are a number of impacts that cannot be valued and therefore are not included in the monetary cost benefit results presented in Chapter 3 of this report. The results from such assessments may, however, be important when considering the relative merits of the different measures and therefore should be considered along with the monetary CBA.

2. The assessments considered in this chapter are listed below. These now include discussion of the impacts of air quality on quality of life and physical activity, which will be taken forward as future work and developed as part of the assessment framework:

   - Exceedences
   - Ecosystems
   - Additional health impacts
   - Quality of life

- Physical activity
- Visibility
- Noise
- Ozone damage to forests
- Distributional (social) impacts
- Acid damage to cultural heritage
- Material damage from NO_X
- Crop damage from SO_2 and NO_X
- Impacts on competition and small businesses

3. The remainder of the chapter describes both the methodology and, where applicable, the results for each assessment. For some assessments, it is possible to present quantified impacts, but for others it is only possible to give an indication of the scale and direction of the effect or to highlight which measures are most likely to be impacted.

4.2 Exceedences

4.2.1 Methodology

4. The national GIS-based modelling methodology has been used to estimate the geographic extent of exceedences of objectives for PM_{10} and NO_2 for the baseline. Chapter 2 includes a description of the methods used and the results for the baseline. The model has also been used to estimate the change in the extent of exceedences resulting from additional measures. Estimates of the impacts on exceedences are shown in Table 4.1 in the next section; estimates can only be shown for those measures for which concentration modelling was undertaken.

5. Owing to changes in the modelling assumptions following the Air Quality Strategy Review Consultation the exceedences estimates for PM cannot directly be compared between the measures to be taken forward in the strategy (C2, E, N and R) and the other measures. While this has been addressed in the monetary CBA it has not been possible to undertake this analysis again for all the measures. The PM exceedence values therefore should only be viewed as indicative for the measures outside the measures to be taken forward.

6. The exceedence table below shows the modelled impact of each of the measures on the most challenging objectives. Baseline results are also shown.

7. The table contains the following information:

   - Impact on exceedences – Background: Modelled percentage change of the area of the United Kingdom that exceeds the objective in 2010 or 2020. This metric reflects average concentrations of the pollutant away from roads.

- Impact on exceedences – Urban Roadside: Modelled percentage change of the length of urban roads in the United Kingdom that exceed the objective in 2010 or 2020. This metric reflects concentrations close to urban roads.

4.2.2 Results

Table 4.1: Impact of additional measures on exceedences of AQS objectives and EU limit values for NO_2 and PM_{10}

Measure	NO_2 40μg.m^{-3} annual mean				PM_{10} <31.5μg.m^{-3} annual mean (equivalent to the 24 hour LV)				PM_{10} <20μg.m^{-3} annual mean (Stage 2 indicative LV)			
	Impact on exceedences in 2010		Impact on exceedences in 2020		Impact on exceedences in 2010		Impact on exceedences in 2020		Impact on exceedences in 2010		Impact on exceedences in 2020	
	B	**R**	**B**	**R**	**B**	**R**	**B**	**R**	**B**	**R**	**B**	**R**
Baseline	**0**	**18.2**	**0**	**8.5**	**0**	**2.1**	**0**	**0.3**	**7.9**	**77.6**	**2.6**	**60.5**
Measure A (Euro low)	0	18.0	0	4.8	0	1.7	0	0	7.7	76.7	1.3	31.1
Measure A2 (Euro revised)	0	17.9	0	3.3	0	2.0	0	0	7.8	77.1	1.5	32.5
Measure B Euro high)	0	17.5	0	1.3	0	1.7	0	0	7.3	74.9	1.0	22.7
Measure C (Early Euro low)	0	17.4	0	4.5	0	1.3	0	0	7.3	74.9	1.3	29.3
Measure C2 (Early Euro revised)	0	17.2	0	3.0	0	1.6	0	0	7.4	76.1	1.4	31.3
Measure D2 (Phase out)	0	17.5	0	8.5	0	2.0	0	0.3	7.7	77.3	2.6	60.5
Measure E (LEV)	0	18.1	0	7.7	0	2.1	0	0.3	7.2	77.5	2.6	58.9
Measure F (Road Pricing)	0	18.1	0	7.1	0	2.1	0	0.1	7.9	77.6	2.4	58.8
Measures G2, G3 (LEZs, London & 7 cities)	0	17.9	0	8.5	0	1.4	0	0.3	7.9	77.4	2.6	60.5

B – km^2 at background (per cent exceeding)

R – km of urban roads (per cent exceeding)

Measure	NO_2 40μg.m^{-3} annual mean				PM_{10} <31.5μg.m^{-3} annual mean (equivalent to the 24 hour LV)				PM_{10} <20μg.m^{-3} annual mean (Stage 2 indicative LV)			
	Impact on exceedences in 2010		Impact on exceedences in 2020		Impact on exceedences in 2010		Impact on exceedences in 2020		Impact on exceedences in 2010		Impact on exceedences in 2020	
	B	**R**	**B**	**R**	**B**	**R**	**B**	**R**	**B**	**R**	**B**	**R**
Baseline	**0**	**18.2**	**0**	**8.5**	**0**	**2.1**	**0**	**0.3**	**7.9**	**77.6**	**2.6**	**60.5**
Measure J (Domcom NO_X)	0	18.2	0	8.1	0	2.1	0	0.3	7.8	77.5	2.5	60
Measure K2 (LCP)	0	17.4	0	8.3	0	1.7	0	0.3	5.7	75.2	2.2	58.6
Measure L (SCP)	0	18.2	0	8.2	0	2.1	0	0.3	7.9	74.9	2.4	59.7
Measure N (Shipping)	0	18.2	0	8.4	0	1.7	0	0.2	5.7	74.9	1.6	52.3
Measure O (Early Euro low + LEV)	0	17.4	0	8.8	0	1.2	0	0	7.2	74.9	1.3	28.7
Measure P (Early Euro low + SCP)	0	17.4	0	4.1	0	1.3	0	0	7.3	74.9	1.2	28.3
Measure Q (Early Euro low + LEV + SCP)	0	17.4	0	3.5	0	1.2	0	0	7.2	74.9	1.2	27.5
Measure R (Early Euro revised + LEV + Shipping)	0	17.1	0	2.6	0	1.4	0	0	6.4	74.7	1.1	26.5

B – km^2 at background (per cent exceeding)

R – km of urban roads (per cent exceeding)

4.2.2.1 Exceedences at roadside

PM_{10} 24 hour limit value

8. The most effective measures are Measures A (Euro low), A2 (Euro revised), B (Euro high), C (Early Euro low), C2 (Early Euro revised), O, P, Q and R (combined measures). These are projected to eliminate all exceedences at roadside of the 24 hour PM_{10} limit value in 2020. The baseline exceedence is 0.3% of urban road length. Measures N and F might have a significant impact on exceedences but are not projected to remove them completely. The remaining measures are likely to have no impact in 2020.

PM_{10} stage 2 indicative limit value

9. There are widespread exceedences of this target at roadside projected for the baseline. The most effective measures are Measures B (Euro high), C (early Euro low), O, P, Q and R (combined measures). These might reduce exceedences by 50% or more, although no measures are likely to achieve 20µg.m^{-3} at roadside everywhere.

NO_2 annual mean

10. The most effective measures are Measures A2 (Euro revised), B (Euro high), C2 (Early Euro low), O, P, Q and R (combined measures); these are projected to reduce exceedences at roadside by more than 50% in 2020. None of the measures are likely to remove all exceedences of this objective in 2020.

4.2.2.2 Exceedences at background

PM_{10} stage 2 indicative limit value

11. Only this target is projected to be exceeded at background in 2010 and 2020. The most effective measures are Measures A (Euro low), B (Euro high), C (Early Euro low), O, P and Q (combined measures). These might reduce exceedences by over 50% in 2020, although no measures are likely to achieve 20µg.m^{-3} everywhere.

4.3 Ecosystem assessment

4.3.1 Methodology

12. The potential benefit offered by the selected additional measures to the protection of ecosystems was assessed through their impact on exceedence of critical loads. Further details on the importance of critical loads as a policy tool, including details on the current situation, are discussed in Volume 2, Chapter 1 of the Air Quality Strategy 2007.

13. An initial screening assessment of the potential additional policy measures was undertaken to identify those with a potentially significant impact on critical loads exceedences, and those with little or no potentially significant impact. Those measures which made significant reductions to sulphur and nitrogen oxide emissions had the greatest impact, while those addressing other pollutants, such as hydrocarbon or primary particle emissions, had no potential impact. None of the measures increased critical loads exceedences, and none had any significant impact on ammonia emissions.

14. Following this initial screening assessment, ten measures were chosen to undergo further assessment, with modelling results selected for 2020 only. The measures selected for full assessment were A (Euro low), A2 (Euro revised), B (Euro high), C (Early Euro low), C2 (Early Euro revised), K2 (LCP long term), N (Shipping), O, P, Q and R (combined measures). These ten measures, alongside the baseline 2020 measures were modelled using the Fine Resolution Atmospheric Multi-pollutant Exchange (FRAME) model.[1] Baseline future emissions estimates were supplied by Netcen for the year 2020 and were used to generate scaling factors for each source type. These scaling factors were then used to convert the 2002 emissions maps to a 2020 scenario.

15. Maps of wet and dry deposition of oxidised sulphur, oxidised nitrogen and reduced nitrogen were generated at a 5 km resolution for three vegetation types: moorland, forest and grid-averaged deposition by the FRAME model and these were used as input for the calculation of critical load exceedences.

16. The assessment of the impact of additional measures on critical loads exceedences is based on a comparison of maps of critical loads and deposition loads. Deposition maps from the Concentration-Based Estimated Deposition (CBED) model were generated to reflect the historic picture, whereas the FRAME model was used for future measures. The CBED model generates UK maps of wet and dry deposition and direct cloud droplet/aerosol deposition on the basis of site measurements of gas concentrations and deposition. Meteorology from 2001-2003 was used to model the current situation as the use of three year averaged meteorological data can minimise inter-annual variations.[2]

17. The results were calculated for both the reduction in the area over which the critical load is exceeded and the magnitude of these exceedences. The problem with only comparing the measures by area (or percentage area) exceeded is that the differences between the measures tend not to be very great and there is therefore little difference across the range of measures. When summing up the areas exceeded, the area is included whether the critical load is only just exceeded, or exceeded by a large amount. Two measures could give the same area exceeded, but the magnitude of exceedence (and therefore the deposition values, and deposition reductions required) could be very different.

18. Accumulated exceedence (AE) can be calculated in order to integrate the area exceeded with the magnitude of exceedence, and so can be a more useful measure for comparing the results. However, large areas with a small exceedence could lead to the same AE value as a smaller area with a larger exceedence. For example (AE = exceeded area * exceedence):

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1 Further details on the FRAME model can be found at http://www.frame.ceh.ac.uk/index.html

2 Further details on the methodology used for the generation of UK critical load maps can be found at http://www.critloads.ceh.ac.uk

Table 4.2: Example calculation of accumulated exceedence for ecosystems assessment (I)

Exceeded habitat area (ha)	Exceedence (keq/ha/yr)	AE (keq/yr)
1000	0.1	100
100	1	100

19. Not all large habitat areas will have small exceedences or all small habitat areas have large exceedences. The results could therefore be:

Table 4.3: Example calculation of accumulated exceedence for ecosystems assessment (II)

Exceeded habitat area (ha)	Exceedence (keq/ha/yr)	AE (keq/yr)
1000	1	1000
100	0.1	10

20. In the assessment, both areas exceeded and AE are used to assess the magnitude of the benefit which could be expected from each measure. The differences in area exceeded (rather than percentage area) are important, deposition could go up or down and the area exceeded not change. AE is useful in taking into account the magnitude of the exceedence, especially where the area exceeded may be the same or similar.

21. All the remaining measures from the proposed list (D (Phase out), E (LEV), F (Road pricing), G (LEZ), H (Retrofit), I (Domcom coal), J (Domcom NO_X), K1 (LCP short term), L (SCP), M (VOC)) were deemed to have an insignificant effect on reducing critical load exceedences compared to the baseline for 2020. These measures were not subject to modelling using FRAME.

4.3.2 Results

22. For each measure, separate results are presented for acidity and nutrient nitrogen deposition. These are shown in Tables 4.4 and 4.5 respectively. For each of these, four figures are shown:

- exceeded area: this is the UK land area (in km^2) for which the critical load would be exceeded, assuming the measure is added on to the baseline scenario, i.e. the effect of the baseline + measure
- % reduction against baseline: the additional benefit, beyond the baseline, of the measure in percentage terms, i.e. % area exceeded in 2020 under the baseline minus % area exceeded under the baseline + measure
- accumulated exceedence: given in $keq.year^{-1}$, this is a combination of area exceeded and magnitude of exceedence for the baseline plus the measure, i.e. area of exceedence of the baseline + measure (in km^2) x deposition above critical load for that area of baseline + measure (in $keq.km^{-2}.year^{-1}$)
- % reduction against baseline: the additional benefit, beyond the baseline, of the measure in percentage terms, i.e. % accumulated exceedence in 2020 under the baseline minus % accumulated exceedence under baseline + measure

Table 4.4: Impacts of additional measures on acidity in ecosystems[a]

	area exceeded for critical loads (km^2)	% reduction against baseline	accumulated exceedence of critical load (keq/yr)	% reduction against baseline
Baseline	30,742	–	1,875,050	–
Measure A (Euro low)	30,204	1.8	1,797,517	4.1
Measure A2 (Revised Euro)	30,985	2.8	1,606,566	7.6
Measure B (Euro high)	29,583	3.8	1,708,937	8.9
Measure C (Early Euro low)	30,183	1.8	1,793,724	4.3
Measure C2 (Early revised Euro)	30,925	3.1	1,597,835	8.1
Measure K2 (LCP)	29,767	3.2	1,750,900	6.6
Measure N (Shipping)	30,040	2.3	1,815,902	3.2
Measure O (Early Euro low + LEV)	30,093	2.1	1,779,281	5.1
Measure P (Early Euro low + SCP)	30,003	2.4	1,768,364	5.7
Measure Q (Early Euro low + LEV + SCP)	29,911	2.7	1,755,295	6.4
Measure R (Early revised Euro + LEV + Shipping)	30,114	5.6	1,530,107	12.0

[a] For those measures modelled using FRAME.

Table 4.5: Impacts of additional measures on nutrient nitrogen deposition in ecosystems[a]

	area exceeded for critical loads (km^2)	% reduction against baseline	accumulated exceedence of critical load (keq/yr)	% reduction against baseline
Baseline	35,789	–	2,771,792	–
Measure A (Euro low)	34,819	2.7	2,665,562	3.8
Measure A2 (Euro revised)	34,258	3.4	2,391,228	7.3
Measure B Euro high)	33,906	5.3	2,543,587	8.2
Measure C (Early Euro low)	34,755	2.9	2,660,327	4.0
Measure C2 (Early Euro revised)	34,200	3.7	2,378,710	7.8
Measure K2 (LCP)	34,029	4.9	2,616,583	5.6
Measure N (Shipping)	35,556	0.6	2,752,724	0.6
Measure O (Early Euro low + LEV)	34,580	3.4	2,640,500	4.7
Measure P (Early Euro low + SCP)	34,608	3.3	2,643,873	4.6
Measure Q Early Euro low + LEV + SCP)	34,473	3.7	2,625,908	5.3
Measure R (Early Euro revised + LEV + Shipping)	33,769	4.8	2,346,770	9.0

[a] For those measures modelled using FRAME.

23. From these results it can be seen that Measures A2 (Euro revised), B (Euro high), C2 (Early Euro revised), K2 (LCP long term), N (shipping), O, P, Q and R (combined measures) have the greatest benefits in terms of acidity. Measures A (Euro low), A2 (Euro revised), B (Euro high), C (Early Euro low), C2 (Early Euro low), K2 (LCP long term), O, P, Q and R (combined measures) have the greatest benefit in terms of nutrient nitrogen.

4.4 Additional health impacts

4.4.1 Methodology

24. The criteria for inclusion of further health impacts in the non-monetary assessment section is as follows:

- a clear consensus that a particular health impact is linked with a relevant pollutant;
- no threshold (if there was a threshold at a known level, concentration modelling data specific to that threshold would need to be available which is not usually the case);
- availability of data (preferably concentration data) to allow judgements on which measures are most important for the relevant pollutant;
- some indication of the relative importance of the health outcome for one pollutant compared with another (to be able to judge the net effect when one pollutant increases and another decreases); and
- whether the health impact has not been quantified (quantified further health impacts are included in the sensitivity analysis chapter).

4.4.1.1 Respiratory symptoms

25. For several of the classical pollutants (particles, ozone, sulphur dioxide and nitrogen dioxide), there is clear consensus that they are linked with increases in respiratory symptoms in children and adults. However, there is less consensus about whether these effects occur down to low concentrations and whether, for example particles have a more potent effect on respiratory symptoms than ozone or vice versa. The latter point is important because several measures show decreases in particles but increases in ozone. Thus, respiratory symptoms were not felt to meet all the criteria for a qualitative assessment and will be discussed in Chapter 5.

4.4.1.2 Lung function

26. The same pollutants have been linked with decreases in lung function but similar points apply. In addition, it is unclear whether small decreases in lung function, particularly in those not suffering from respiratory disorders, have clinical significance. This will also be discussed in Chapter 5 along with some more uncertain health outcomes.

4.4.1.3 Carcinogens

27. The carcinogenic air pollutants benzene, 1,3-butadiene and PAHs meet the criteria for qualitative assessment outlined in paragraph 24 – there is consensus that they are carcinogens, they are not regarded as having thresholds and quantification has not been undertaken. These are discussed in more detail below.

4.4.1.4 Benzene

28. Exposure of workers to high concentrations of benzene at industrial sites in the past has shown a link with leukaemia in adults.[3] Benzene is not considered to affect childhood leukaemia.[4] Benzene is a genotoxic carcinogen and is considered to have no threshold. It is, therefore, possible that if any of the additional measures reduce benzene concentrations, there would be some resulting health benefits. These are likely to be small since leukaemia is quite rare and the changes in benzene concentrations are likely to be small. It is not possible to quantify this effect directly as the shape of the concentration-response relationship at environmental levels is unknown (the health studies only relate to high occupational exposures).

29. The likely effect of the various measures on benzene is used to give a qualitative indication of possible small additional health benefits (see Table 4.6 below). Traffic is a significant source of benzene; Measure D (Phase out) is likely to have the greatest impact on this pollutant.

30. High exposures to 1,3-butadiene have been linked to leukaemia and lymphoma in workers at industrial sites.[5] 1,3-butadiene is a genotoxic carcinogen and is assumed to have no threshold. Thus, additional health benefits might occur with any measures which lead to reductions in 1,3-butadiene concentrations. These are likely to be very small but cannot be quantified directly as the shape of the concentration response is unknown at environmental concentrations.

31. The likely effect of the various measures on 1,3-butadiene concentrations is used to give a qualitative indication of possible small additional health benefits (see Table 4.6 below). Traffic is a significant source of 1,3-butadiene; Measure D (Phase out) is likely to have the greatest impact on this pollutant.

4.4.1.5 Polycyclic aromatic hydrocarbons (PAHs)

32. Exposure of workers to high concentrations of polycyclic aromatic hydrocarbons (PAHs) has been shown to cause lung cancer.[6] PAHs are genotoxic carcinogens and are considered to have no threshold. Thus, additional health benefits might occur with measures that reduce PAH concentrations. The size of these benefits cannot be quantified directly as the slope of the concentration-response function is unknown at environmental concentrations, but it is probably small.[7]

33. The likely effect of the various measures on PAH concentrations is used to give a qualitative indication of possible additional health benefits (see Table 4.6 below). Traffic is thought to be only a minor source of B[a]P (B[a]P, as explained in section 2.4

[3] 'Benzene', Expert Panel on Air Quality Standards, Department of Environment (1994a). Available at: http://www.defra.gov.uk/environment/airquality/aqs/benzene/index.htm

[4] 'Statement on the Review of the Possible Associations between Childhood Leukaemia and Residence Near Sources of Traffic Exhaust and Petrol Fumes', Committee on Carcinogenicity of Chemicals in Food, Consumer Products and the Environment, Department of Health (2005). Available at http://www.advisorybodies.doh.gov.uk/coc/childleukaemia.htm

[5] 'Second Report on 1,3-butadiene', Expert Panel on Air Quality Standards, Defra (2002). Available at: http://www.defra.gov.uk/environment/airquality/aqs/13butad_2nd/index.htm

[6] 'Polycyclic Aromatic Hydrocarbons', Expert Panel on Air Quality Standards, DETR (1999b). Available at: http://www.defra.gov.uk/environment/airquality/aqs/poly/index.htm

[7] The ACS study (Pope et al 2002) showed an association between $PM_{2.5}$ and lung cancer. The reason for this is unknown but PAHs on the surface of particles could be involved.

of Chapter 2 is used as a marker compound for total PAH emissions) and therefore transport measures are likely to have very little impact (traffic is an important source of naphthalene, which is a PAH, but is not one of the significant carcinogenic PAHs). In terms of B[a]P, Measure I (Domcom coal) is likely to be the most effective measure.

4.4.1.6 Lead

34. Lead is known to damage the developing nervous system and blood lead concentrations have been shown to be inversely related to IQ.[8] There is no apparent threshold for this effect. Blood lead concentrations have been shown to be related to air lead concentrations. There is also evidence to suggest that raised blood lead concentrations are related to increased blood pressure. The data is not sufficient to allow quantification of the effects of outdoor air lead concentrations on health in the UK. Lead levels have been reducing substantially so the size of the current effect due to lead in air is probably very small. It is unlikely that any of the measures considered in this review will have an impact on lead emissions.

4.4.2 Results/conclusions

35. The results and conclusions of the additional health impact assessment, for the pollutants discussed above, are presented in Table 4.6 below. For measures not presented there is either an unknown impact or no impact on benefits.

Table 4.6: Results of the additional health impacts assessment

Measure	**Benzene** Leukaemia (rare)	**1,3-butadiene** Lymphoma, leukaemia (rare)	**PAHs** Lung cancer
Measure D (Phase out)	Possible small reduced risk of leukaemia	Possible small reduced risk of lymphoma/ leukaemia	–
Measure I (Domcom coal)	–	–	Possible small reduced risk of lung cancer

36. It is difficult to comment on these results. They clearly make the point that there are some additional benefits that have not been quantified for some of the measures. It is hard, however, to judge how important the additional benefits are in comparison with the quantified benefits. Some of these additional benefits could be very small. The measures were not optimised on the basis of reducing the pollutants covered here but for the pollutants covered in the main analysis. In addition, the size of the resulting effect on health may differ in number and severity. As a rough guide, leukaemia is less common than lung cancer. In conclusion, this qualitative assessment indicates that there are additional health benefits to be taken into account but these may be small.

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[8] Lead', Expert Panel on Air Quality Standards, Department for the Environment Transport and the Regions (1998). Available at: http://www.defra.gov.uk/environment/airquality/aqs/lead/index.htm

4.5 Quality of Life

37. There may be less tangible impacts of poor air quality on quality of life. For example, a 2003 survey of a National Asthma Panel by Asthma UK, reported that 42% of people with asthma felt that traffic fumes prevented them from walking or shopping in congested areas, and 39% felt that traffic fumes discouraged them from exercising. This is likely to be difficult to quantify as it would need to be known what degree of reduction in traffic fumes would be necessary to generate a given improvement in quality of life. In general terms, measures which impact most on traffic emissions (A, A2, B, C, C2), may lead to some improvement in the quality of life experienced by asthmatics.

4.6 Physical activity

38. Some of the measures discussed may have effects on physical activity. Increasing physical activity in the population can decrease levels of heart disease. We recommend further work, both on the impact of the measures on physical activity and on the feasibility of quantifying the effect of any changes in physical activity on health.

4.7 Visibility

4.7.1 Methodology

39. The word 'visibility' in this context relates to a reduction in visual range caused by the presence of air pollutants in the atmosphere. The problem is associated largely with particles and NO_2. At pollutant levels typical of Europe and North America this can lead to impacts on amenity in terms of reduced enjoyment of landscapes.

40. Analysis in the USA has concluded that reduced visibility is a significant impact of air pollution. In Europe, however, the association of air pollution with reduced visibility has received very little attention. There are several possible reasons for this. Perhaps the most important is that there have been significant improvements in visibility already across much of the UK and Europe.

41. Following a review of quantification methods for visibility impacts[9] it has been concluded that there is an inadequate base of UK or European data on which to base a credible assessment. The impact of additional measures on visibility has therefore not been conducted within this analysis.

4.8 Noise

4.8.1 Methodology

42. Noise affects amenity and numerous surveys have shown it to be a major nuisance. It may also lead to a number of health impacts through a variety of direct and indirect effects, though there is considerable debate on the reliability of the evidence.

[9] Holland et al (2005) 'Final Methodology Paper (Volume 1) for Service Contract for Carrying Out Cost-Benefit Analysis of Air Quality Related Issues, in Particular in the Clean Air for Europe (CAFE) Programme', prepared for EC-DG Environment. Available at http://www.cafe-cba.org/

43. There are agreed approaches for the quantification and valuation of noise on amenity, especially in the transport sector. To complete such assessments, however, would require accurate modelling of the specific areas affected, baseline traffic flows and speeds, the levels of noise reductions from alternative fuel and vehicle types etc. Quantification and valuation of the noise impacts for Measure F (Road pricing) and Measure G (LEZ) was undertaken as part of the original modelling work and the findings are referenced here. For other measures, the quantification of noise benefits has not been undertaken, although it is expected that noise benefits will be extremely small in relation to other benefits. The key potential noise impacts are highlighted in Table 4.7 below.

4.8.2 Results

44. Table 4.7 shows the main noise impacts that might be expected from the measures assessed in this review. Measures O, Q and R (combined measures) would also benefit from the effects of Measure E.

Table 4.7: Results of noise assessment

Measure	Effect on noise
Measure D (Phase out)	Reduction in noise since older vehicles have higher engine noise than modern vehicles. For example, pre-Euro cars only had to comply with a noise limit of 77 dB, whereas Euro II/III cars had to comply with a noise limit of 74 dB.
Measure E (LEV)	Reduction in noise: some low emission vehicles may have lower noise emissions
Measure F (Road Pricing)	Modelling for the Road Pricing Feasibility Study for the measure considered in this report suggested noise benefits of around 6% of total environmental benefits, equivalent to less than 1% of total benefits. These benefits are included in the total monetary estimates shown for this measure in the monetary CBA.
Measure G (LEZ)	Similar, though less dramatic, effects to Measure D

4.9 Ozone damage to forests

4.9.1 Methodology

45. The effect of ozone on forests provides an area where there is potential for future quantification. Karlsson et al (2004)[10] investigated the response of a forest stand in Sweden to predicted ozone concentrations and found that they had the potential to reduce forest growth by 2.2% and economic returns by 2.6%. Extrapolating this to the national level provided an overall estimate of lost forest production of €56 million per year in response to ozone exposure. These estimates were specific to timber and pulp production and did not account for other benefits that might be provided by forests. It has not been possible to apply this approach in this review, though the original study provides some guide to the potential magnitude of the effect.

[10] Karlsson et al (2005) 'An Economic Assessment of the Negative Impacts of Ozone on Crop Yield and Forest Production at the Estate Ostad Sateri in South-West Sweden', Journal of the Human Environment, 31(1), pp.32-40

4.10 Distributional (social) issues

46. The existing evidence linking air quality and distributional (i.e. social and socio-economic) effects has been assessed and used as the basis of a qualitative assessment of the measures included within this review.

47. There is evidence from UK studies[11, 12] that shows that air pollution exposure is higher among some communities who rate poorly on social deprivation indices (i.e. in deprived areas). This work was limited in scope, covering only five urban areas in the UK. An comprehensive study for the whole of the UK is ongoing.

48. Interim analysis of this study suggests that the associations between poor air quality and deprived areas are complex and depend on the pollutant in question. For example, concentrations of NO_2 and PM_{10} tend to be relatively high in more deprived areas in England but not in Wales, where concentrations are relatively high in the least deprived areas. There are also some non-deprived areas in England that have poor air quality. In Northern Ireland and Scotland, there is no clear pattern.

49. The trend for ozone is the inverse of NO_2, with relatively low concentrations experienced by the most deprived areas[13] (except for Wales). This is because average ozone concentrations are generally higher outside urban areas.

50. For SO_2, concentrations are largely driven by the location of large point source, except in Northern Ireland, where the most prominent source is the residential combustion of solid fuels. In England and Northern Ireland, the most deprived communities experience relatively higher concentrations. In Wales, the opposite is the case, whilst in Scotland the trend is relatively flat across all groups.

51. The distributional impact of air quality policies is influenced not only by divergent impacts but also by differing responses to those impacts. For example, if deprived communities are experiencing disproportionately high concentrations relative to other groups in society, and are also more susceptible to the impacts resulting from these concentrations, then the inequalities may be compounded. This could be because such communities have a higher susceptibility to poor air quality (e.g. a higher proportion of people with respiratory illness) or less access to mitigation, through the purchase of medicines and access to good quality health care.

52. European and US studies have shown variation in the susceptibility of different groups to health impacts. For example, Hoek et al (2002)[14] has observed possible links between air pollution impacts and low educational attainment, although these

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[11] King, K. and Stedman, J. (2000) 'Analysis of Air Pollution and Social Deprivation', report for the Department for the Environment, Transport and the Regions, The Scottish Executive, The Welsh Assembly and the Department of Environment for Northern Ireland. Available at http://www.airquality.co.uk/archive/reports/cat09/aeat-r-env-0241.pdf

[12] Pye, S. (2001) 'Further Analysis of NO_2 and PM_{10} Air Pollution and Social Deprivation', Oxford: AEAT. Available at http://www.aeat.co.uk/netcen/airqual/reports/strategicpolicy/2001socialdeprivation_v4.pdf

[13] Deciles are used to give a ranking by splitting the indices of social deprivation into ten groups.

[14] Hoek et al (2002) 'The Association Between Mortality and Indicators of Traffic-Related Air Pollution in a Dutch Cohort Study', Lancet, 360, pp.1203–1209

were not statistically significant. Brunekreef (1999)[15] found higher susceptibility to air pollution effects amongst subjects with poorer nutrition. The re-analysis of the ACS cohort study on the long term effects of particles on mortality by the Health Effects Institute (2000) also found increased risks in people with lower educational status.

53. The ongoing work is also looking at the marginal change in air pollution from 2003 to 2010, to determine the impact of existing policies.

54. Given the findings of the previous sections, there is considerable uncertainty about the possible distributional impacts of the measures being proposed in the Air Quality Strategy. However, a qualitative assessment of the different measures is presented in Table 4.8, based on the known impacts of the various measures.

Table 4.8: Results of distributional impact assessment

Measure	Possible distributional impact
Measures A (Euro low), A2 (Euro revised), B (Euro high), C (Early Euro low), C2 (Early Euro revised), E (LEV), F (Road pricing), H (Retrofit)	General benefits in terms of reducing roadside concentrations. Possibly greater benefits to more deprived areas in reducing high air quality concentrations.
Measure D (Phase out)	Likely to be benefits in reducing roadside concentrations, possibly greater benefits to more deprived areas in reducing high air quality concentrations. Wider distributional benefits than general policies above, as lower income groups tend to drive older cars.
Measure G (LEZ)	Likely to be benefits in reducing roadside concentrations, possibly greater benefits to more deprived areas in reducing high air quality concentrations. Possible higher benefits to more deprived areas, as targeted in urban centres.
Measure I (Domcom coal)	Likely to have very strong distributional benefits (especially in Northern Ireland).
Measures J (Domcom NO_X), L (SCP)	Possible higher benefits to more deprived areas, has more effect in urban areas.

55. It is likely that Measures D (Phase out), G (LEZ) and I (Domcom coal) would have the greatest potential benefits to more deprived areas. The other transport measures would possibly also have benefits, particularly in reducing those exposed to highest air pollution (which correlates with deprivation). Measure J (Domcom NO_X) and L (SCP) could also have potential benefits as they are likely to have more effect in urban areas. Such impacts would also affect Measures O, P, Q and R (combined measures).

[15] Brunekreef, B. (1999) 'All but Quiet on the Particulate Front', American Journal of Respiratory and Critical Care Medicine, 159, pp.354-356

4.11 Acid damage to cultural heritage

56. The same approach that is used for quantifying damage to modern buildings could, in theory, be applied to cultural and historic buildings. However, in practice there is a lack of data at several points in the impact pathway approach with respect to the stock at risk and valuation.

57. Nevertheless, valuation studies of cultural heritage show that people place a significant economic value on cultural heritage (see the review by Navrud and Ready, 2002).[16] This data could potentially be used in an extended framework to illustrate the potential significance of damage to cultural heritage. Another approach for informing decision makers that has been developed by ICP Materials is based on assessment of 'acceptable rates' of deterioration, on the basis that materials left in the open air will be damaged even in the absence of air pollution. A NEBEI workshop, will address the issue of damage to cultural heritage from air pollution more generally.

58. For this analysis, the potential damage to cultural heritage has not been assessed, in part due to the methodological problems, but also because in general, anticipated benefits will be low as most measures do not involve changes in SO_2 emissions. Those measures that do have an effect on SO_2 concentrations and therefore may have a positive impact on damage to cultural heritage are: Measure I (Domcom coal), Measure L (SCP), Measure N (Shipping) and Measures P, Q and R (combined measures).

4.12 Crop damage from SO_2

59. The pollutants most implicated in acid damage are SO_2 (most importantly), followed by ozone. Both of these have been quantified in the main analysis.

60. The role of atmospheric NO_2 in material damage has not yet been clarified. Although a strong synergistic effect with SO_2 has been observed in laboratory studies, this has not yet been observed in the field. NO_2 is not included in the ICP exposure-response functions for material damage and so quantification is not appropriate. Material corrosion does occur from wet deposition (from secondary pollutants formed from NO_X emissions). However, the importance of this pollutant is now considered much less than the effect of dry deposition of SO_2 (the most recent ICP materials analysis shows less effect from wet deposition than the earlier literature in this area), and so we have not assessed these impacts. There may be some small additional benefits to materials from the reduction in wet deposition from NO_X emissions reductions; these will be related to the relevant reductions in NO_X emissions for each measure.

4.13 Crop damage from SO_2 and NO_X

61. Ozone is recognised as the most serious air pollutant problem for the agriculture and horticulture sectors. The effects on agriculture from ozone in the UK have been quantified in the main analysis.

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[16] Navrud, S. and Ready, R. (eds.) (2002) 'Valuing Cultural Heritage. Applying Environmental Valuation Techniques to Historical Buildings, Monuments and Artefacts', Cheltenham, UK: Edward Elgar

62. Other pollutants are not as important, though some potential effects are possible. The effects of SO_2 can be both positive and negative, through both direct and indirect mechanisms, and include changes to soil acidity (via deposition), and crop fertilisation from deposition. Previous studies have developed impact-pathway approaches (e.g. earlier ExternE studies). At very high concentrations, SO_2 can damage crops, but previous analysis as part of the appraisal of the Air Quality Strategy[17] has shown that in monetary terms, such effects are negligible at current concentrations.[18] They have not been assessed here.

63. Direct effects of NO_2 on crops have been reported, but not at the concentrations found in the UK. Accordingly, such effects are not considered here. Nitrogen deposition to agricultural land might be expected to enhance productivity given that it is applied by farmers to crops, but when crops are fertilised at the recommended rate, the effect of applying more nitrogen is negligible.

64. There are other possible effects from all pollutants from interactions with pests and pathogens, though quantification (and qualitative assessment) is not possible.

4.14 Impacts on competition and small businesses

4.14.1 Methodology

65. The possible competition impacts of a number of the measures within the Strategy have been assessed. It has not been practicable to undertake a full, detailed competition assessment across all affected markets. Therefore, the likely competition impacts have been assessed in mainly qualitative terms based on a quantitative and qualitative understanding of the affected markets, the current market structure and nature of competition and the likely positive and negative impacts of the possible policy measures. The analysis has been driven by the availability and detail of the data and information.

66. For the small business impact, a qualitative assessment has been made based on the expected market impacts.

67. Given that the measures in this report do not yet have full implementation plans and that any measure that is taken forward would be subject to a full RIA, both the competition and small business assessments should be considered preliminary.

4.14.2 Results

4.14.2.1 Competition results

68. The main potential impacts are highlighted below:

69. **Measure A (Euro low), Measure A2 (Euro revised) and B (Euro high):** The main markets affected would be vehicle and engine manufacturers/suppliers; manufacturers and suppliers of exhaust after treatment systems; and owners/operators of vehicles.

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[17] An Economic Analysis of the National Air Quality Strategy Objectives: An Interim Report of the Interdepartmental Group on Costs and Benefits', Department of the Environment, Transport and the Regions (1999a).

[18] In fact, there may be a very small beneficial effect from current SO_2 concentrations.

These measures would not be expected to alter market structures in general, although if the standards necessitate particular technologies, those producing alternative abatement techniques may be excluded from the market. The strength of competition among manufacturers/suppliers could potentially be affected, depending upon the technologies required. No significant effects on innovation would be expected; indeed innovation by UK and EU firms may be stimulated by the requirements.

70. **Measure C (Early Euro low) and Measure C2 (Early Euro revised):** The key markets affected would be essentially the same as those for implementation of the standards under Measures A (Euro low) and B (Euro high). Such incentives would be unlikely to alter the current vehicle and engine manufacture/supply market structure given that all suppliers would be subject to the same incentive mechanisms. While such early incentives could create disparities between the UK and other countries, it is understood that German, Austrian and Dutch governments have already tabled plans for such fiscal incentives, with France and Sweden having expressed an interest.

71. The potential competition effects are as follows:

- Manufacturers may have to produce a greater range of models to satisfy both markets with and without incentives for vehicles meeting the voluntary standards (with potentially significant costs and higher unit costs due to smaller production runs). It may also prove difficult to pass on cost increases to (non-EU) markets that are not subject to the same requirements;
- In terms of suppliers of abatement equipment, firms that manufacture the required technologies will have a competitive advantage over those that do not and could gain a greater market share potentially reducing competition; and
- Firms owning/operating vehicles that are able to take advantage of these incentives (e.g. in fleet renewal) may gain an advantage over those that are required to purchase vehicles after the incentivisation period has ended (this might also mean slightly higher start-up costs for new entrants to the market, in the short term at least).

72. All of these effects are expected to be small.

73. **Measure D (Phase out):** This measure is not expected to impact on competition as the option proposes incentives to owners or operators of existing vehicles only and as such it is unlikely such incentives would alter the current vehicle manufacture and supply market structure. In addition, only a small number of vehicles will be affected by this option.

74. **Measure E (LEV):** This measure would incentivise replacement of certain petrol and diesel cars with low emission vehicles. It would affect manufacturers/suppliers of vehicles/engines, as well as vehicle owners and operators.

75. In the short term, this measure may favour the small number of companies currently supplying LEVs to the UK market (though several other manufacturers are currently developing their own models). In the longer term however, the number of firms manufacturing and supplying LEVs should increase thus increasing the strength of competition, improving customer choice and encouraging innovation. Recent EU

proposals on CO_2 targets for passenger cars by 2012 include reaching a proposed 130g/km target through technology based improvements and a further 10g/km (taking the target to 120g/km) reflecting further measures, such as biofuels.

76. **Measure F (Road pricing):** The Road User Pricing feasibility study[19] estimated considerable net benefits to businesses. The results of the study suggested that, in aggregate, the value of time savings for freight and business car travellers would exceed the amount that they would have to pay in charges. This is because people travelling on behalf of their employer tend to value their time highly. Potential impacts on labour supply were highlighted as the higher costs of many commuter car trips might affect the distance workers are willing to travel. There may also be a potential concern for treatment of non-UK vehicles on UK roads: competition may be affected if all vehicles are not treated equally.

77. **Measure G (LEZ):** The impact on competition is based on the assessment that was carried out as part of Transport for London's Strategic Review of the Feasibility Study for London's LEZ.[20] This option would affect fleet operators of vehicles who operate predominately or solely in the urban areas covered by the LEZ option and also disproportionately impact fleet operators of specialist vehicles (specialist vehicles are more expensive than conventional fleet vehicles and therefore tend to have longer replacement cycles). This measure could affect the structure of the second hand vehicle market as the presence of an LEZ would reduce the re-sale value of older vehicles (i.e. that do not meet the emissions criteria for the LEZ), affecting both operators and leasing companies. In addition, this measure could benefit suppliers of equipment such as DPFs, and provide a spur to innovation in emissionreducing equipment.

78. **Measure H (Retrofit):** This is likely to be accomplished through incentive schemes; it will mainly affect suppliers of abatement equipment and owners/operators of vehicles. The measure could potentially exclude suppliers of alternative abatement technologies from the market. It should not reduce the strength of competition between vehicle operators/owners, provided that it is voluntary.

79. **Measure I (Domcom coal):** A 100% switch in domestic combustion from coal to gas (or oil where applicable) might change the structure of the domestic fuel supply market, forcing suppliers of coal out of the market. However, this should be seen in the context of a baseline increase in the proportion of gas in the UK's domestic combustion fuel mix, to a point where gas significantly dominates the fuel mix under baseline trends. Customer choice and differentiation would be affected where usage of coal (or oil) is no longer allowable due to this measure, though this represents a small and declining part of the overall market. A more detailed assessment would need to look at the various suppliers of alternative fuel types, the market for maintenance and supply services, and how these related markets are affected.

80. **Measure J (Domcom NO_X):** The market for gas boilers appears to be relatively uniform across the EU, and regulation that would affect all of these installations

[19] 'Feasibility Study of Road Pricing in the UK', Department for Transport (2004a). Available at http://www.dft.gov.uk/stellent/groups/dft_roads/documents/divisionhomepage/029798.hcsp

[20] Watkiss et al (2003) 'A Summary of the Phase 2 Report to the London Low Emission Zone Steering Group', Oxford: AEA Technology. Available at http://www.tfl.gov.uk/tfl/low-emission-zone/pdfdocs/phase-2-feasibility-summary.pdf

simultaneously would be assumed to impact little on the competitive outcomes on the intra-EU competitiveness front. However, there is a need to assess the structure of the gas boiler market within each geographical area in order to establish whether there are any significant impacts arising from this measure. It has not been possible to conduct this analysis at the detailed level required to ensure that no significant adverse impacts will follow. There are also related markets in maintenance services that may need to be considered. An additional issue relates to existing boilers, the manner in which they would be phased out, and how the market for these boilers would be affected by the new regulation.

81. **Measure K (LCP):** The UK has a proportionately greater reliance on coal-fired electricity generation than other countries. If UK installations have to fit SCR and other countries do not, this will impact on the relative profitability of these installations relative to those which fall outside the scope of this measure. For the long term measure (K2), the plants in the non-electricity generating sector, refining, iron and steel might be allowed to operate under a cap and trade scheme, in which case the industry will adopt a cost-effective means of implementing this measure. It is difficult to model the impact of these alternative outcomes, given that it is too early to say what the final implementation route might be. A full assessment of the competitiveness impact would look at all the installations affected and how this measure will be implemented. If all the plants have to individually fit abatement equipment (SCR) then there is a likelihood that the manufacturing sector (iron and steel and refineries) would face more competitiveness issues than their electricity-sector counterparts (since extra costs could be passed onto final electricity consumers).

82. **Measure L (SCP):** This measure would affect a range of markets and installations (such as power generation, autogenerators, various industrial sources, public services and others), and the market for alternative abatement technologies so it has not been possible to define individual markets in any detail. The measure (introduced through a future directive) should affect market structures equally across Europe, but the national implications would only be understood with a more detailed assessment of the composition of plants affected and how these differ between Member States. In the best case scenarios, all EU-based firms would be equally affected – though non-EU firms would not be affected. An additional issue that would need consideration is that those installations below the minimum threshold for inclusion (<20MW) might gain an advantage over those above the threshold.

83. **Measure M (VOC):** This option proposes a reduction in national VOC emissions based on a range of different measures and as such it is difficult to present an overall assessment of the competition impacts of this option.

84. **Measure N (Shipping):** This measure would affect petroleum refineries producing fuel for shipping, bunker suppliers, shipping operators, as well as ship and abatement technology manufacturers/suppliers. However, it would affect all ships globally that are above the specified size threshold. It would not be expected to affect market structure significantly, nor create significant barriers to entering/exiting the market (though new firms may face higher initial capital outlay).

85. **Measure O:** This would affect competition in line with the competition effects

discussed above for Measures C and E.

86. **Measure P:** This would affect competition in line with the competition effects discussed above for Measures C and L.

87. **Measure Q:** This would affect competition in line with the competition effects discussed above for Measures C, E and L.

88. **Measure R:** This would affect competition in line with the competition effects discussed above for Measures C2, E and N.

89. The results from the initial analysis have highlighted Measures G (LEZ), I (Domcom coal), and K (LCP) as having competition issues that may warrant further investigation although without a more detailed understanding of implementation options it is difficult to clearly assess the effects. In addition, there may be other measures that, when analysed in more detail, may raise competition concerns.

4.14.2.2 Small business impacts

90. **Measures A (Euro low), A2 (Euro revised) and B (Euro high):** While the burden upon smaller manufacturers may be proportionately larger, it is envisaged that the EU vehicle type approval framework directive could be employed, in order to limit the effects of measures on manufacturers whose world-wide production is less than 500 units per annum.

91. **Measure G (LEZ):** The LEZ measure could have a disproportionate effect on small businesses. The views of small businesses were assessed as part of Transport for London's Scheme Order Consultation.[21] The associated Economic and Business impact assessment identified three proposal detrimental impacts on smaller businesses, namely is suggested to potentially have negative impacts on small business, as:

- they may be less aware of their best options to manage the cost of compliance (i.e. they would not necessarily know whether their business would be better off fitting a filter or replacing their vehicles);
- they may not plan sufficiently far ahead, and as a result may need to pay higher costs for making more of their fleet compliant in a shorter time span; and
- they may not be able to finance the cash flow requirements of the vehicle replacement process, i.e. buying a compliant vehicle and selling an older vehicle.

92. **Measure I (Domcom coal):** This measure has the potential to have a disproportionate effect on small coal suppliers that supply domestic coal, although the way in which this option is intended to be implemented has not yet been defined. The Small Business Service indicate that, in 2004, there were approximately 40 companies undertaking mining and agglomeration of hard coal in the UK, of which 75% were classified as either micro or small businesses.[22] Given that domestic coal supplies have higher profit

[21] Steer Davies Gleave (2006) ' Proposed London Low Emission Zone – Economic and Business Impact Assessment', available at http://www.tfl.gov.uk/tfl/low-emission-zone/pdfdocs/lez-economic-impact-assessment.pdf.

[22] The SBS statistics define micro businesses as operating with 1-9 employees, with small businesses operating with 10-49 employees. Statistics are available at http://www.sbs.gov.uk/SBS_Gov_files/researchandstats/

margins than industrial supplies, any shift away from domestic could have the effect of lowering profit margins. In addition, there is a possible impact on the anthracite industry as a result of this measure. There may also be significant impacts on the downstream distributors and sellers of coal, and distributors of gas (most of which are network companies which may benefit asymmetrically). This impact will have to be looked at in more detail if the measure is taken forward.

93. **Measure L (SCP):** This measure has the potential to have a disproportionate effect on small businesses. However, given the range of plants/sectors that the measure affects, a detailed view of this has not been possible at this stage. There are a wide array of businesses and linked businesses involved in this measure, and a more detailed assessment would be produced if this measure is taken forward. Any impact identified for Measure L would also impact Measures P and Q (combined measures).

Chapter 5: Uncertainties and sensitivity analysis

KEY UPDATES TO THE CHAPTER

Comments relating to the effect of the different sensitivity analyses on the measures have been updated to refer to the new/revised measures, set out at the beginning of Chapter 3, and recent developments since the last IGCB report. In particular, section 5.3.3.7, on the effect of using other hazard rate reductions, has been updated to reflect COMEAP's most recent views on uncertainty. The following additional analysis has been undertaken following consultation responses and new information:

- An additional sensitivity has been added to take account of **non-linearity of hazard rate reduction** assumptions
- An additional sensitivity has been undertaken in relation to the **social cost of carbon** following the uncertainty arising from the findings of the Stern Review[1]
- Alternative estimates of the technology costs for **Measure H (Retrofit)** have been considered following the substantial change to these figures following the consultation
- To address the significant uncertainty over the long term cost estimates for **Measure N (Shipping)** an alternative scenario has been modelled reducing the duration of this measure to 20 years, and
- Results of **Monte Carlo analysis** carried out to assess the potential distribution of costs and benefits for Measure B (Euro High), Measure H2 (Retrofit) and the new combined Measure R. The results of this analysis can be found in section 5.6 at the end of this chapter.

[1] Full text of the Stern Review is available at www.hm-treasury.gov.uk.

5.1 Introduction

1. This chapter provides details as to the major uncertainties surrounding the main analytical results presented in Chapters 3 and 4. The layout of the chapter is as follows:

    - **Section 5.2** discusses uncertainties in modelling the baseline and the measures and presents the impact of such uncertainties on the results of the exceedences of current objectives;
    - **Section 5.3** discusses uncertainties surrounding the quantification and valuation of benefits and presents results of sensitivity analyses;
    - **Section 5.4** discusses uncertainties surrounding the costs of the different measures and presents results of sensitivity analyses;
    - **Section 5.5** provides a brief overview of the uncertainties in the quantification of the ecosystem results;and

- **Section 5.6** provides discussion and results of the recent Monte-Carlo analysis carried out for selected measures considered by the AQS.

2. The other assessments presented in Chapter 4 provide results at a qualitative level only since it is recognised that the uncertainty surrounding the effects is considerable; no further discussion on the uncertainty of these assessments is therefore provided in this Chapter.

5.2 Uncertainties in modelling the baseline and the measures

3. The assessment presented in this document represents our best estimate of current and future air quality. There are, however, uncertainties associated with the assessment.

4. Volume 2, Chapter 1 of the Air Quality Strategy includes an analysis of the uncertainties associated with the air quality assessment and projections. It also explores the sensitivity of the conclusions drawn from the analysis to uncertainty in assumptions and understanding of pollutant characteristics and behaviour.

5. The following section summarises the conclusions of this analysis.

6. There are three elements that contribute the greatest uncertainty to the main conclusions drawn in this review for the key pollutants nitrogen dioxide (NO_2), particles (PM_{10}) and ozone (O_3). These are:

   - weather in the future which will have a large impact on the extent of exceedences of objectives;
   - uncertainties about the response of PM concentrations to changes in emissions of precursor gases; and
   - uncertainties about the source apportionment of PM.

7. It is not practical to combine all the uncertainties and sensitivities to arrive at an estimate of total uncertainty associated with the analysis for the review of the Air Quality Strategy. It is possible however to identify the key uncertainties that affect the main conclusions of the analysis, i.e. which pollutants are likely to exceed objectives in the future and the effectiveness of additional policies on future concentrations and improving public health.

8. In line with the evidence base section of the Air Quality Strategy, the same energy projections and modelling base year have been used for both documents. For all measures analysed in this report, the UEP 12 energy projections have been used with a 2003 base year. For Measures Q and R, there has been modelling using the UEP 26 energy projections and a 2004 base year. It is noted that this increases the benefits but does not change the conclusions of the cost benefit analysis. Detailed results for R are given in Annex 8.

5.2.1 Future concentrations of NO_2

9. Choice of base year has little impact on the absolute projected attainment or exceedence of objectives for NO_2. It does however have an important impact on the extent of projected exceedences.

10. Furthermore, the independent Air Quality Expert Group (AQEG) noted that future concentrations of NO_2, are likely to be higher than currently projected because of the influence of higher primary NO_2 emissions and the increasing background concentrations of ozone.[1]

11. Consequently we are confident that future NO_2 concentrations will exceed objectives in 2010 and 2020, without further measures. AQEG also concluded that there are likely to be some exceedences of the annual mean objectives and limit value for NO_2 in 2010.

12. AQEG noted that "there are reasons to believe that the current projections for future urban NO_2 concentrations may be optimistic. If northern hemisphere baseline ozone (O_3) concentrations continue to rise and influence rural O_3 concentrations in the UK, then the relationships between urban NO_2 and NO_X concentrations will alter resulting in higher than expected future annual mean NO_2 concentrations. Furthermore, if catalytically-regenerative particulate traps that are being retrofitted to diesel powered vehicles dramatically increase direct emissions of NO_2, as indicated by studies carried out in the USA, there will be further breaches of the air quality objective and limit value".

PM_{10}

13. For PM_{10}, the sensitivity analysis indicates that we can be confident that limited exceedences of the 24 hour objective will still exist near busy roads in 2010 and 2020 but that the annual average 2004 objective will continue to be attained nearly everywhere.

14. It is highly likely that there will be widespread exceedence of an annual average concentration of $20\mu g.m^{-3}$ near to major roads in 2010 and 2020. The extent of exceedence of this concentration at background locations is highly dependent on the weather in any future year and assumptions about the contribution of secondary particulates to PM levels. These two dependencies are related. Consequently we are less confident about the extent of exceedences of $20\mu g.m^{-3}$ in future years.

15. AQEG independently drew similar conclusions that the annual mean limit value set for 2005 would be met nearly everywhere, but with some exceedences of the limit of 35 days with 24 hour averages above $50\mu g.m^{-3}$, especially in London[2]. AQEG also concluded there is likely to be substantial exceedences of $20\mu g.m^{-3}$ near to major roads in 2010.

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[1] 'Nitrogen Dioxide in the United Kingdom', Air Quality Expert Group, Defra (2004). Available at http://www.defra.gov.uk/environment/airquality/publications/nitrogen-dioxide/index.htm

[2] 'Particulate Mater in the United Kingdom', Air Quality Expert Group, Defra (2005d). http://www.defra.gov.uk/environment/airquality/publications/particulate-matter/index.htm

Ozone

16. The ozone modelling presented in the Air Quality Strategy estimates that there will be extensive exceedence of the objective in future years. Measurements show background ozone levels are slowly increasing and that measures to reduce NO_X emissions will increase ozone concentrations in urban areas. Consequently there is a large margin for error in the assessment of future concentrations and we are confident that ozone concentrations will exceed the objective in 2010 and 2020.

5.2.2 Future PM concentrations and health impacts

17. Quantification of health impacts of air pollution is dominated by the impact on mortality of chronic exposure to PM. Calculation of this impact is based on population-weighted concentration of PM. Hence the sensitivity of population weighted concentration to input assumptions is a good indicator of the sensitivity of the estimate of health impacts to the same assumptions.

18. Population weighted PM_{10} concentrations are approximately 10% lower for projections starting in 2002 compared to 2003. In other words, if the weather in 2010 were similar to 2002, the estimated health impacts would be around 10% lower than in the baseline.

19. The impact of measures is not subject to the same degree of base year uncertainty because the change in concentration is relatively independent of the base year.

5.2.3 Effectiveness of measures in the baseline and additional measures

20. There is a significant risk that the effectiveness of measures on PM_{10} concentrations in the baseline and additional measures will be lower than estimated. Consequently there is a real risk that future concentrations of PM_{10} will be higher than forecast. This is because of uncertainties about (1) the composition of the atmosphere in the future; (2) the responsiveness of PM concentrations to changes in precursor gas emissions[3]; and (3) apportionment of sources of PM. This is potentially important because of the influence that changes to population-weighted concentrations have on estimates of health impacts in Chapter 3.

21. Finally it should also be noted that the assessment has been carried out using the best national model available appropriate for a national assessment. However in respect of the cost, benefits assessment and in particular for the compliance with objectives assessment, the national model cannot represent all the possible local exceedences which are often found as a result of local assessment (such as those carried out by Local Authorities and Environment and Highways Agencies) which are by definition only detectable at a more detailed, local level. Likewise the national model may underestimate the impact on air quality of measures at the local scale.

[3] This potential bias has been reduced since the AQSR owing to the change in the assumption regarding the formation of secondary PM, as discussed in Chapter 2, Section 2.4 of this report.

5.3 Benefits

22. The uncertainties that could impact the monetary estimates of the benefits relate to the health impacts. The main analysis in Chapter 3 covered health benefits:

- where there was clear evidence linking the pollutant to the health outcome;
- where all necessary information to allow quantification (e.g. baseline rates) was available; and
- where the Committee on the Medical Effects of Air Pollutants (COMEAP) had recommended a concentration-response coefficient.

23. The qualitative analysis in Chapter 4 covered health benefits where there was clear evidence linking the pollutant to the health outcome but quantification was not possible for one reason or another.

24. The health benefits in this chapter are included for a variety of reasons:

(i) there is uncertainty over whether a particular type of health effect occurs or not. This can be over additional health effects of pollutants already covered or over health effects of pollutants that have not been covered. For example, there is extensive debate over whether NO_2 actually has an effect on respiratory hospital admissions or whether the apparent effect is due to the correlation between NO_2 and PM;

(ii) there is uncertainty over how to quantify a particular health effect e.g. uncertainty as to whether or not there is a threshold; and

(iii) a variety of assumptions can be used as part of the methodology for quantifying health benefits. This chapter explores the effect of the use of some alternative assumptions on the results.

25. Most of these issues are discussed qualitatively but some have been quantified. Ideally, for a cost-benefit analysis, some indication of the relative significance of the non-quantifiable health effects should be given. This depends on a wide variety of different factors including strength of evidence, size of concentration-response function, presence or absence of a threshold, numbers of susceptible people and seriousness of effect. For example, minor effects at an individual level may become important in public health terms if large numbers of people are affected and a weak effect with no threshold may be more important than a strong effect which only occurs above a threshold.

26. The way this section is set out is listed below.[4] It should be noted that not all the alternative possibilities discussed will affect the results to the same degree and some are less likely to apply than others.

(i) Discussion of additional health outcomes

- Respiratory symptoms

[4] Note that health benefits sensitivities are also presented in Annex 8 (health impacts for Measure R using UEP26 2004 modelling) and in Table 5.22 (health impacts for 20 year duration for Measure N).

- Lung function
- A&E visits and GP consultations
- Infant mortality
- Long term exposure and morbidity
- Carcinogenic and neurological effects
- Sulphur dioxide – additional health outcomes
- Sulphur dioxide – effects of long term exposure

(ii) Discussion of the health effects of pollutants that were not covered by the main analysis.

- Nitrogen dioxide (deaths brought forward, respiratory hospital admissions, effects of long term exposure)
- Carbon monoxide
- Benzene, 1,3-butadiene, PAHs and lead
- Dibenzo[a,l]pyrene
- Heavy metals

(iii) Discussion of different methodological assumptions

- Hospital admissions (additional or brought forward)
- Sulphur dioxide short term effects – overlap with particles
- Ozone – additional health effects
- Different coefficients/thresholds for ozone
- Only short term exposure to particles
- Sensitivities in reduction in hazard rate for particles (including non-linear scaling)
- Only primary particles have an effect
- Direct $PM_{2.5}$ modelling
- Adjust long term effects of particles for subject's level of education
- Apply reduction in hazard rate for particles to subjects under 30 years
- Assume long term exposure to particles at different times of life is important
- Assume underlying mortality rates do not remain constant
- Assume a different lag time for long term effects of particles
- No cut-off in 2109 for calculating long term effects of particles
- Incorporate sequential concentration changes for long term effects of particles
- Validity of annual pulse approach for long term effects of particles
- Inclusion of trans-boundary effects

(iv) Discussion of the sensitivities around the values used to monetise the benefits

- Health valuation
- Social cost of carbon

5.3.1 Some additional health outcomes

27. The sections below discuss some possible additional health outcomes that might be associated with air pollution. It should be noted that this is discussed in terms of whether or not there is some evidence for effects on the relevant health outcome and therefore a possible additional health benefit. These benefits are only 'possible' because for quantification there ideally needs to be not just some evidence, but a consistent body of evidence. There also needs to be evidence that the air pollutant will be associated with the health outcome at the relevant air pollutant concentration, not just at any concentration. These points need to be borne in mind when reading the sections below.

5.3.1.1 Respiratory symptoms

28. It is accepted as likely that air pollution has an effect on respiratory symptoms in children and adults. The evidence for this has been reviewed in earlier reports from the Department of Health Advisory Group on the Medical Aspects of Air Pollution Episodes (MAAPE), COMEAP and the Expert Panel on Air Quality Standards (EPAQS).[5] This evidence was updated briefly in COMEAP's 1998 report on quantification (Department of Health, 1998). This applies to particles, ozone, sulphur dioxide and, to a lesser extent, nitrogen dioxide (for which the evidence on short term exposure and respiratory symptoms is more inconsistent).

29. Respiratory symptoms are harder to quantify than deaths brought forward or hospital admissions because it is necessary to know:

    (i) the size of the relevant subject group in the UK (e.g. asthmatics of a particular level of severity); and

    (ii) the baseline rate of the symptom in question in the relevant subject group (e.g. average numbers of days with cough per year in mild asthmatics).

    Neither type of information is easily obtained.

30. There are also fewer panel studies in a greater variety of subject groups and UK studies may not be available. COMEAP did not recommend quantification of respiratory symptoms for any of the pollutants in 1998, although this may be reconsidered during the current update of this report by COMEAP. Respiratory symptoms have not therefore been quantified in this report.

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[5] See Department of Health Advisory Group on the Medical Aspects Air Pollution Episodes (MAAPE) reports on ozone, sulphur dioxide and nitrogen dioxide (Department of Health, 1991; 1992; 1993), and Committee on the Medical Effects of Air Pollutants (COMEAP) 1995 report on Non Biological Particles and Health (Department of Health, 1995b). See also Defra Expert Panel on Air Quality Standards (EPAQS) 1994, 1995, 1996 and 1995/2001 reports on ozone, sulphur dioxide, nitrogen dioxide and particles respectively (Department of Environment, 1994b; 1995a; 1995b; 1996 and DETR, 2001) (all available at http://www.defra.gov.uk/environment/airquality/aqs/).

31. If it is assumed that the effect of air pollution on respiratory symptoms or lung function has no threshold (this is not firmly established but there is some evidence for it), then the effects will be proportional to the size of the pollution reduction. The uncertainty over this was the reason why this endpoint was not covered in the qualitative assessment. There is indirect evidence that there may not be a threshold for the effects on respiratory symptoms. This is because the time series evidence for the more severe endpoints (deaths brought forward and respiratory hospital admissions) does not, in general, appear to have a threshold and it seems unlikely that these endpoints would occur without accompanying symptoms.

32. If it is assumed that respiratory symptoms track with respiratory hospital admissions, then, for particles, Measure A (Euro low), Measure A2 (Euro revised), Measure B (Euro high), Measure C (Early Euro low), Measure C2 (Early Euro revised) and the combined measures (Measures O, P, Q and R) would have the greatest additional benefits. For ozone, Measure M (VOC) would be best although the additional benefits are probably small. An additional complication is that reductions in respiratory hospital admissions due to particles are often countered by increases in respiratory hospital admissions due to ozone (because nitric oxide is often reduced at the same time as particles and nitric oxide is an ozone scavenger).[6] A net reduction is usually still present if there is a threshold for ozone but if there is no threshold the increase in respiratory hospital admissions due to ozone is often greater than the reduction due to particles. If respiratory symptoms follow this pattern, then it is hard to judge the net effect on respiratory symptoms, but a net increase in respiratory symptoms is certainly possible. However, in overall terms this is a more minor effect than the gain in life years from reductions in particles.

33. There is also some mixed evidence of an effect of air pollutants on medication used to treat symptoms. The arguments relating to this are analogous to those on respiratory symptoms.

5.3.1.2 Lung function

34. The evidence on reductions in lung function is somewhat similar to that on respiratory symptoms and the evidence has been reviewed in many of the same reports. A particular issue with lung function is that small reductions may have no clinical importance and pass unnoticed by the individual. On the other hand, some individuals may experience larger changes or a small reduction may matter more in someone whose baseline lung function is already reduced. Chamber studies of small numbers of healthy volunteers or mild asthmatics suggest thresholds but it is unclear whether these would apply at the population level. For example, studies of ozone in farm workers or vigorously exercising cyclists show effects on lung function down to quite low concentrations (WHO, 2004a). COMEAP did not recommend quantification of effects on lung function in 1998. The likely influence of this effect on the benefits analysis is complicated by the uncertain importance of small changes, the presence or absence of a threshold and the opposing direction of particle and ozone benefits. Small additional benefits, an insignificant effect and small additional disbenefits are all possible.

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[6] This applies particularly in urban areas. The balance between a decrease in hospital admissions due to particles and an increase in hospital admissions due to ozone will depend on the measure and the relative amount of PM and NO_X (which indirectly affects ozone). This balance may change in future with changes in, for example, precursor levels.

5.3.1.3 A&E visits and GP Consultations

35. There are studies available from London showing effects of sulphur dioxide, nitrogen dioxide and particles (but not ozone) on A&E visits for respiratory complaints (Atkinson et al, 1999) and for various pollutants on GP consultations for asthma in adults and children (Hajat et al, 1999). Although just a single study in each case, the studies are large and are directly relevant to the UK health care system. There have been other studies of this type in other places but the number of studies is much smaller than for hospital admissions or deaths brought forward. The above papers were published after the last COMEAP report on quantification in 1998 and will be considered in the forthcoming update of this report. If the effects on these health outcomes were to be recommended for quantification, it is likely that they would be most important for the measures relating to Euro Standards (Measures A, A2, B, C and C2) and the combined measures (Measures O, P, Q and R) which have the greatest positive impact on NO_2 and PM_{10}.

5.3.1.4 Infant mortality

36. The number of studies on air pollutants and infant mortality were relatively few but have increased in recent years. COMEAP has not considered this issue in any detail but plans to do so now that the WHO report on the effects of air pollution in children has been published (WHO, 2005). There is the potential for this effect to have large effects on life expectancy in individual cases, but this is not automatically the case overall (background infant mortality rates are low). If air pollution does have this effect, then it is likely to be directly proportional to concentrations of the relevant air pollutant and is more likely to be related to particles (although there is some evidence for other pollutants). Therefore, measures that give good health benefits due to particles (the measures relating to Euro Standards (Measures A, A2, B, C and C2), shipping (Measure N) and the combined measures (Measures O, P, Q and R)) may have some additional health benefits due to possible reductions on the effect on infant mortality.

5.3.1.5 Long term exposure and morbidity

37. COMEAP did not consider that the evidence on chronic morbidity for any of the pollutants was sufficiently robust for quantification in 1998. Since the mechanism for the effect of long term exposure to particles on mortality is not understood it is unknown whether or to what degree an effect on chronic morbidity is involved. An effect on chronic morbidity has the potential to have marked effects on quality of life and on NHS costs unless only a very small number of people are affected. Although studies of chronic morbidity are more difficult to undertake than studies of short term effects, they have the potential to remove a substantial area of uncertainty. COMEAP is currently updating its view on the effects of long-term exposure to air pollution on morbidity.

5.3.1.6 Carcinogenic and neurological effects

38. These are discussed under the relevant pollutants in the qualitative assessment in Chapter 4 (section 4.4).

5.3.1.7 Additional health outcomes for sulphur dioxide

39. The effect of sulphur dioxide on deaths brought forward and hospital admissions was incorporated in the main analysis. There is some evidence that sulphur dioxide is also associated with most of the health outcomes discussed earlier in this section, although COMEAP did not consider the evidence was sufficient for quantification in 1998. There is clear evidence from chamber studies that sulphur dioxide causes bronchoconstriction in asthmatics but, as these are based on small groups of volunteers rather than population samples, this evidence is harder to use for quantification. This is discussed further in Vol. 2 Chapter 1 of the AQS. If these effects were to be quantified, then they are most likely to be important for Measures I (Domcom coal), L (SCP), N (Shipping) and P, Q and R (combined measures).

5.3.1.8 Long term exposure to sulphur dioxide and mortality

40. The ACS study[7] found an association between long term exposure to sulphur dioxide and mortality. This was discussed earlier in Chapter 2, section 2.5.3 of this report. If this association is real (as opposed to acting as a marker for particles) then a small additional gain in life years might be expected for Measures I (Domcom coal), L (SCP), N (Shipping) and P, Q and R (combined measures). The increments are likely to be small as sulphur dioxide concentrations are already quite low.

5.3.2 Pollutants for which benefits were omitted from the main analysis

5.3.2.1 Nitrogen dioxide

41. No direct health benefits for nitrogen dioxide were included in the main analysis. Nitrogen dioxide may be associated with some of the health outcomes discussed in the previous section, although the results are sometimes inconsistent. Sections 5.3.2.2 to 5.3.2.4 describe the possible effects of nitrogen dioxide on deaths brought forward and respiratory hospital admissions. They also cover the long-term effects of nitrogen dioxide.

5.3.2.2 Nitrogen dioxide – deaths brought forward

42. In 1998, COMEAP did not recommend quantification of the effects of nitrogen dioxide on deaths brought forward. Although associations were seen with all-cause mortality in the first APHEA study (Toulumi et al, 1997), associations were not seen with either cardiac or respiratory mortality (Zmirou et al, 1998). This issue will be reconsidered in the forthcoming update of the 1998 report.

5.3.2.3 Nitrogen dioxide – respiratory hospital admissions

43. In 1998, COMEAP did not recommend quantification of the effect of nitrogen dioxide on respiratory hospital admissions but suggested quantification as a sensitivity analysis. There is uncertainty over whether the associations seen between nitrogen dioxide and

[7] Pope et al (2002).

respiratory hospital admissions in fact represent nitrogen dioxide acting as a marker for the effect of particles. Nitrogen dioxide and particles are closely correlated. This issue will also be considered further in the forthcoming update of the 1998 report. In the meantime, nitrogen dioxide and respiratory hospital admissions has been included in the quantitative sensitivity analysis for this report.[8]

44. For most of the measures where both ozone and nitrogen dioxide impacts have been presented (except K2 (LCP)), the decrease in respiratory hospital admissions due to nitrogen dioxide is greater than the increase in respiratory hospital admissions due to ozone. The size of this possible additional direct benefit of nitrogen dioxide is greatest for the measures relating to Euro Standards (Measures A, A2, B, C and C2) and the combined measures (Measures O, P, Q and R)

45. The nitrogen dioxide respiratory hospital admissions have then been valued using the central valuations for respiratory hospital admissions shown in Table 2.9 in Chapter 2. The inclusion of this effect has a minimal impact on the overall cost benefit results. For example, Measure B shows the greatest impact on NO_2 hospital admissions, reducing them by 780 cases per annum; this has the effect of increasing the benefits for Measure B in the range of £2.5-£12m p.a.

5.3.2.4 Nitrogen dioxide – effects of long term exposure

46. The most recent COMEAP view is that long term exposure to nitrogen dioxide does not have an impact on mortality. The main US cohort study (Pope et al, 2002) did not find an effect of nitrogen dioxide. The forthcoming COMEAP quantification report on morbidity will address the issue of long-term exposure, including consideration of some of the more recent studies described below.

47. The WHO long term guideline for nitrogen dioxide (NO_2) was originally set on the basis of studies suggesting increased respiratory symptoms in people living in households with gas stoves, although these studies are somewhat inconsistent. More recently (WHO, 2004a) the guideline was reconfirmed, partly due to additional evidence of an effect on children's respiratory symptoms in a study in California (McConnell et al, 2003). An effect linked to organic carbon was also found. Similar results were found in another Californian study on lung function growth (Gauderman et al, 2000; 2002).

48. There is continuing debate over whether these effects are due to nitrogen dioxide itself or due to the correlation between nitrogen dioxide and particles. However, in one Californian study (McConnell et al, 2003), the effects of both organic carbon and nitrogen dioxide were maintained in two pollutant models and, in the other (Gauderman et al, 2002), the effect of nitrogen dioxide, in two pollutant models was more robust than measures of particles. In addition, there is evidence from animal studies using high doses of nitrogen dioxide that long term exposure can have an effect on the lung. There remains some uncertainty over the extent to which nitrogen dioxide is acting directly or as an indicator for traffic pollution but, on balance, WHO decided to reconfirm the guideline.

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[8] An updated sensitivity analysis has been published alongside this report.

49. It is hard to judge the likely impact of this effect if it were to be quantified. On the one hand, respiratory symptoms are a less serious effect than deaths brought forward or hospital admissions. On the other hand, respiratory symptoms are more common and might affect larger numbers of people. Individual measures which show the greatest reductions in nitrogen dioxide are Measure A (Euro low), Measure A2 (Revised Euro), Measure B (Euro high), Measure C (Early Euro low) and Measure C2 (Early Euro revised).

5.3.2.5 Carbon monoxide

50. COMEAP did not recommend quantification of the effects of carbon monoxide. There is some time-series evidence of an effect on deaths brought forward and hospital admissions but it is unclear whether this is due to carbon monoxide or due to the correlation between carbon monoxide and particles. If the effect is due to carbon monoxide, and there is no threshold, then there would be some additional health benefits from any carbon monoxide reductions which occur. This is most likely to be true for Measures D (Phase out), G (LEZ) and possibly other transport measures.

5.3.2.6 Benzene, 1,3-butadiene, PAHs and lead

51. The possible effects of these pollutants were discussed in the qualitative assessment section in Chapter 4 of this report.

5.3.2.7 Dibenzo[a,l]pyrene

52. Dibenzo[a,l]pyrene (DB[a,l]P) is a polycyclic aromatic hydrocarbon (PAH) that is possibly up to 100 times more potent a carcinogen than benzo[a]pyrene.[9] However, it has been difficult to measure in the past (Coleman et al, 2001) so there is currently very little information on sources of DB[a,l]P. It is not possible in this analysis to judge whether any of the measures reduce levels of DB[a,l]P. More analytical work on levels of this PAH would be useful.

5.3.2.8 Heavy metals

53. Heavy metals have not been addressed in any detail in this assessment. Heavy metal exposure tends to be less widespread than for some of the common traffic pollutants, for example. It is possible that fuel switching from coal to gas (Measure I) will reduce arsenic emissions by a small amount but arsenic emissions from coal are small in any case. This small reduction might have a small benefit on reducing lung cancer, but this is unlikely to be significant compared with other causes of lung cancer. It is possible that part of Measure K (LCP) might result in a small increase in nickel emissions since refineries are a significant source of nickel and SCR increases fuel consumption. Nickel has been linked with respiratory effects and lung cancer, although the precise form of nickel involved may be important. Overall, changes in heavy metals are unlikely to have any marked effects on the results.

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[9] 'Carcinogenicity of Dibenzo[a,l]pyrene', Committee on Carcinogenicity of Chemicals in Food, Consumer Products and the Environment, Department of Health (2003). Available at http://www.advisorybodies.doh.gov.uk/coc/dbp.htm

5.3.3 Varying methodological assumptions

54. This section discusses the effect of varying specific assumptions used when quantifying the effects of the pollutants covered in the main analysis (particles, sulphur dioxide and ozone). The effect of some of these variations have been quantified and the results of this are discussed in the relevant section.

5.3.3.1 Hospital admissions – additional or brought forward

55. The main analysis has assumed that the hospital admissions are additional. The time-series studies cannot distinguish whether the extra hospital admissions counted on higher air pollution days are additional or would have occurred anyway at a later date. There is no information available to judge which is the case or whether the balance is towards mainly additional or mainly brought forward hospital admissions. It is only possible to note that this is an uncertainty that could reduce the size of the benefits to a small degree.

5.3.3.2 Sulphur dioxide – double counting of short term effects with effects of particles

56. The short term effects of sulphur dioxide on deaths brought forward and respiratory hospital admissions have been calculated separately from the effects of particles in the main analysis. COMEAP noted in 1998 that the effects were not necessarily additive and that there could be some double-counting involved in quantifying these pollutants. If the apparent effect of sulphur dioxide is, in fact, due to particles, then the sulphur dioxide results should be excluded. This would result in only a small decrease in benefits for Measures I (Domcom coal), L (SCP), N (Shipping) and combined Measures P, Q and R.

5.3.3.3 Ozone – additional health effects

57. Many of the possible additional health outcomes discussed in section 5.3.1 may apply to ozone. Ozone has not been modelled for all the measures, but, for most of the measures modelled, ozone is increased rather than decreased. This is because any measure that reduces nitric oxide emissions will lead to less scavenging of ozone and an increase in ozone in urban areas towards levels found in rural areas. Thus, particularly if the effects of ozone have no threshold, these measures could increase health effects due to ozone.

58. On the whole, these possible health effects are smaller than the effects of long term exposure to particles on life expectancy, so the increases do not completely negate the overall health benefits of reductions in effects of other pollutants. However, the increasing ozone concentrations might have greater overall importance if long term exposure to ozone had an effect on mortality. Interim discussions by COMEAP during preparation of the ozone report suggested that the evidence for this was weak but could not be ruled out. This view needs to be confirmed during finalisation of the ozone report and during discussions for the quantification report. There are particular complications for ozone since ozone levels are low indoors such that ambient ozone concentrations may be worse at representing personal exposures to ozone than for some other pollutants. It is worth noting that, should further work suggest that there was an effect on long term exposure to ozone and mortality, then this could have a marked effect on the conclusions of the main analysis.

5.3.3.4 Ozone – different coefficients and thresholds

59. In the main analysis, only the effects of ozone on deaths brought forward and respiratory hospital admissions were quantified. The sensitivity analysis here examines two issues – the size of the concentration-response coefficient and the level of a possible threshold. These were discussed in Chapter 2, section 2.5.2 of this report. Briefly, a concentration-response coefficient for mortality of 0.3% per 10µg.m^{-3} ozone from a more up to date WHO meta-analysis (WHO, 2004b) was used for quantification. A similar calculation was not done for respiratory hospital admissions because the WHO meta-analysis did not give an all ages coefficient. In addition, calculations were done assuming a cut-off of 35 ppb rather than zero or 50 ppb. This cut-off has been used in European cost benefit analysis calculations (partly because European ozone modelling is more uncertain below this level). It is also a level that distinguishes between increases in ozone due to reduced scavenging from nitric oxide (which mainly occurs below 35 ppb) and increased photochemical production of ozone (which mainly occurs above 35 ppb).[10]

60. Using a coefficient of 0.3% rather than 0.6% for mortality halves the number of deaths brought forward. However, this has little overall effect as most measures are dominated by the impact of particles: when the resultant ozone impacts are valued, the impact on the NPV figures is minimal; this sensitivity does not switch the NPV for any measure.

61. Using a threshold of 35 ppb gives an answer intermediate between the zero and 50 ppb thresholds; the valued benefits using a 35 ppb threshold lie within the existing range. The results do illustrate that a substantial portion of the no threshold result for ozone is due to changes at low ozone concentrations (due to less nitric oxide scavenging) rather than changes as a result of increased photochemical activity. Thus, when considering ozone health impacts alone, the view on whether ozone has health effects at low concentrations is very important. However, as mentioned above, in overall terms, the benefits are still dominated by the effects of particles.

5.3.3.5 Particles

62. Particles may be associated with many of the additional health outcomes discussed in section 5.3.1. This could result in additional health benefits but these would be less in terms of total public health impact[11] than the benefits from the long term effects of particles.

5.3.3.6 Effects of only short term exposure to particles on life years lost

63. It is possible that some unknown confounders could account for the apparent effect of long term exposure to particles on mortality. This is becoming increasingly unlikely as a wider range of studies of the effect of long term exposure to particles are published. Nonetheless, this unlikely possibility, has been considered as part of this sensitivity analysis to illustrate that some effects on mortality would still be quantified. Even if longer term exposure carried no additional risks, then the evidence for an effect on mortality from large numbers of time-series studies would still stand. These have been calculated as deaths brought forward using the same method as

[10] Full sensitivity analysis has been published alongside this report.

[11] The total number of people affected may be greater for more minor health outcomes such as respiratory symptoms.

for other effects of short term exposure as described in section 2.5.2 in Chapter 2. For the long term measures, the deaths brought forward per year as a result of the concentration reduction in 2010 were added for the first 5 years, those as a result of the concentration reduction in 2015 were added for the next 5 years followed by those as a result of the concentration reduction in 2020 for 90 years. This gave a total for deaths brought forward over the 100 year period. For short term measures, the calculation was truncated according to the lifetime of the policy.

64. For comparison with the long term effects, a rough estimate of the life years gained from a reduction in the acute effects can be made with some assumptions about the likely loss in life expectancy from a death brought forward. The loss of life expectancy involved in a death brought forward is actually unknown although some evidence suggests it is likely to be at least a month or two (Schwartz, 2000; Zeger et al, 1999; Samet et al, 2000). COMEAP chose to use a range of 2 to 6 months on average per death brought forward (Department of Health, 2001b). Once this assumption is made, the total loss of life expectancy attributable to short term exposure to particles is derived simply by multiplying the calculated reductions in numbers of deaths brought forward by 2 to 6 months.[12]

65. The results show that, for the long term measures, the life years gained from the short term effects only are substantially lower than the lowest estimate of life years for the long term effects. This supports the now widely accepted view that longer term exposure is the main driver of the public health impact. The life years gained from the short term effects are also substantially lower for the short term measures although this may not be by exactly the same proportion as for the long term effects.

66. The assumption that there are no chronic mortality effects from particles has a major impact on the cost benefit results. For many of the measures (e.g. the measures relating to Euro Standards (Measures A, A2, B, C and C2), K (LCP), L(SCP), and the combined measures (Measures O, P, Q and R) the net benefits become negative under these assumptions: the carbon and ozone disbenefits outweigh the other health benefits, included the acute mortality effects from reductions in particles.

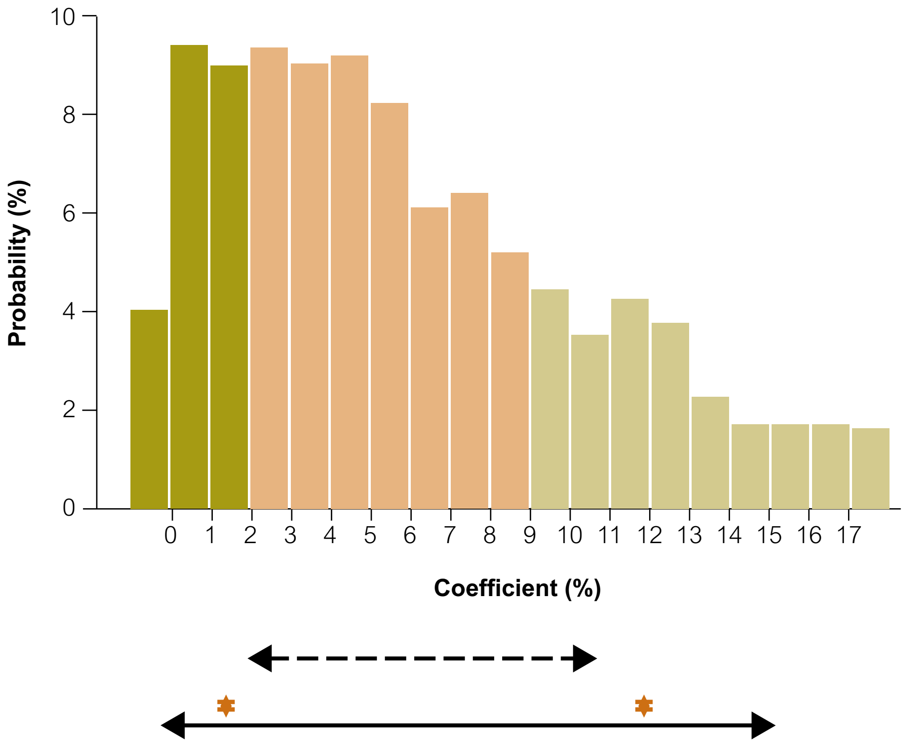
5.3.3.7 Uncertainties and sensitivities in % reduction in hazard rate per μg.m^{-3} $PM_{2.5}$ including linear and non-linear scaling

67. The main recommendation from COMEAP (Department of Health, 2006b; Department of Health, 2007) of a 0.6% hazard rate reduction per μg.m^{-3} $PM_{2.5}$ from the recent update of the ACS study (Pope et al 2002) is based on an estimate using the average of measurements in 1979-1983 and 1999-2000. The 95% confidence interval for this estimate is 0.2% to 1.1% hazard rate reduction per μg.m^{-3} $PM_{2.5}$. This represents only the statistical (sampling) uncertainty. There are also other estimates from the Pope et al (2002) study (for different measurement periods and with other statistical models). In addition, there are results from other studies. For example, evidence from several more recent studies suggests that, when analyses are carried out at a smaller spatial scale than the metropolitan areas of the ACS study, estimated coefficients were even larger than the upper 95% confidence interval from the Pope et al (2002) study. Thus, there are wider uncertainties involved in the choice of a hazard rate reduction than just the

[12] The results are provided as part of full sensitivity analysis for this report.

statistical (sampling) uncertainty. COMEAP took this into account by asking individual members to assign probabilities to the likelihood of the hazard rate reduction exceeding a specified value, taking into account various factors, including those listed above. The aggregate probabilities from the members (derived using the arithmetic means of the individual probabilities) were then used to define an uncertainty distribution (see Figure 5.1 below)[13].

Figure 5.1



The first bar represents the probability of the coefficient being 0 or less (no adverse effect) and the last bar of it being more than 17%.

The coloured bars of the histogram indicate the quartiles of the distribution: dark green – the 1st quartile, regarded as the 'low' band of the distribution; brown – the 2nd and 3rd quartiles, regarded as the 'middle' band of the distribution; and light green – the 4th quartile, regarded as the 'high' band of the distribution.

◄- -► 1.06 (1.02 – 1.11) relative risk of death of all-cause mortality and 95% statistical sampling confidence interval (CI) per 10 µg/m^3 $PM_{2.5}$ (as published by Pope *et al*, 2002).

◄—► 1.06 (1.00 – 1.15) relative risk of death of all-cause mortality and members' 95% plausibility interval per 10 µg/m^3 $PM_{2.5}$.

✱ These indicate the typical 'low' (1%) and 'high' values (12%) suggested for use in sensitivity analysis. They represent the 12.5th and the 87.5th percentiles of the overall plausibility distribution.

13 Figure 5.1 is taken from the draft full COMEAP report.

68. This figure shows, for possible values of the coefficient in the range 0-17%, the average probability assigned by members. For example, on average a 4% probability was assigned to the coefficient being zero or less (left-most bar), about a 9% probability was assigned to the coefficient being above 0 but not more than 1, i.e. including 1 (second bar), and so on.

69. The entire distribution provides the best representation of uncertainty although it can be summarised in various ways. For example, the 95% uncertainty interval is from 0% to 15%. This is wider than the 95% confidence interval of 2% to 11% from the Pope et al (2002) study, as would be expected from the fact that a wider range of uncertainties have been taken into account. Note that only providing information on the 95% uncertainty interval omits the information in Figure 5.1 on the probabilities assigned to particular values between 0% and 15%.

70. For the purposes of sensitivity analysis, the best approach is to include the full probability distribution of the range of potential hazard rate reductions in a Monte Carlo analysis. This has indeed been included, along with other factors, in the Monte Carlo analysis presented in section 5.6 below. A simpler approach is to use alternative low and high values either side of the central estimate. COMEAP defined a 'typical low' value and a 'typical high' value as the median[14] of the lowest quartile (1%) and the highest quartile (12%) respectively[15]. This is illustrated in Figure 5.1. Note that this is not intended to be used as a range that encompasses the full range of possible values for the coefficient[16]. The method of calculation using these 'typical low' and 'typical high' sensitivities is identical to that for the other hazard rate reductions.[17]

71. The use of the 1.2% reduction in hazard rate per $\mu g.m^{-3}$ $PM_{2.5}$ (12% per $10\mu g.m^{-3}$) increases the chronic mortality benefits in an almost linear manner[18] i.e. the chronic mortality benefits are nearly twice as large as the values when assuming a 0.6% per $\mu g.m^{-3}$ hazard rate reduction. The use of a 0.1% reduction in hazard rate per $\mu g.m^{-3}$ $PM_{2.5}$ (1% per $10\mu g.m^{-3}$) gives benefits a sixth of the size when assuming a 0.6% per $\mu g.m^{-3}$ hazard rate reduction. Comparison of the life years calculated using linear scaling with those calculated using non-linear scaling shows that linear scaling overestimates the results by only 0 to 1.5% for the 0.1% reduction in hazard rate per $\mu g.m^{-3}$ $PM_{2.5}$; by about 2-3% for the 0.6% per $\mu g.m^{-3}$ hazard rate reduction and by about 4-6% for the 1.2% reduction in hazard rate per $\mu g.m^{-3}$ $PM_{2.5}$ (see webtables for life years results). Table 5.1a sets out the impacts of using 'typical low' and 'typical high' sensitivities on the net present values of each of the measures. Table 5.1b provides the non linear estimates of net present values of the measures that used concentration modeling.[19]

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14 The 12.5th and 87.5th percentiles of the whole distribution.

15 Note that use of the outer ends of the 95% uncertainty interval (0% and 15%) would be misleading in this context as these are 'atypically' low and 'atypically' high values with low probabilities (see Figure 5.1).

16 There is a 1 in 4 chance that the true value of the coefficient lies below 1% or above 12%.

17 These results are also part of the full sensitivity analysis (see footnote 10).

18 Linear scaling is a reasonable approximation for the small coefficients and small concentration changes used in most of the analysis in this report. Where changes are larger, the more precise equation is based on multiplicative scaling of the original study RR (relative risk), taken here as 1.06 for an original concentration change of 10 $\mu g/m^3$. If the new concentration change in population-weighted mean for the policy of interest is $-x$ $\mu g/m^3$ (with a negative sign as the analysis usually concerns reductions), then the new RR is calculated as $1.06^{-x/10}$. The new RR derived can then, as a percentage change, be multiplied by the standard factor to give the desired result.

19 Owing to the time constraint it was not possible to calculate the non linear estimates for the measures calculated using damage costs, measure D1, G, H, I, and K1. In comparison with linear estimation, non linear estimation on average reduces the life years by around 3% for the 6% coefficient. Some of these measures give very small but positive NPVs for no lag. These could just switch to negative with non-linear scaling but this does not alter the main conclusions that these measures are borderline.

Table 5.1a: NPV of all measures using typical low and typical high hazard rate reductions using linear scaling

Net present value (£millions)	Central		Typical low		Typical High	
	No lag	40 yr lag	No lag	40 yr lag	No lag	40 yr lag
Measure A	801	80	(215)	(352)	2020	598
Measure A2	539	(264)	(599)	(751)	1905	320
Measure B	514	(432)	(795)	(990)	2085	237
Measure C	947	148	(216)	(367)	2343	766
Measure C2	595	(246)	(617)	(777)	2049	391
Measure D1	(3)	(4)	(5)	(5)	(1)	(3)
Measure E	112	63	44	34	194	98
Measure G1	(1)	(33)	(15)	(43)	16	(21)
Measure G2	(2)	(67)	(28)	(85)	29	(46)
Measure G3	(12)	(14)	(18)	(18)	(5)	(9)
Measure H1	(17)	(33)	(60)	(62)	34	2
Measure H2	0	(5)	(12)	(12)	14	6
Measure H3	2	(7)	(21)	(22)	27	11
Measure I	(15)	(23)	(37)	(38)	11	(5)
Measure J	(148)	(179)	(189)	(195)	(102)	(159)
Measure K1	34	(107)	(102)	(200)	195	4
Measure K2	(139)	(232)	(265)	(285)	12	(168)
Measure L	57	18	3	(5)	122	46
Measure N	576	245	99	42	1149	489
Measure O	978	186	(186)	(337)	2374	813
Measure P	1000	163	(215)	(374)	2458	807
Measure Q	1053	203	(180)	(341)	2533	856
Measure R	1211	33	(488)	(705)	3250	919

Table 5.1b: NPVs of measures using concentrations data and using non-linear scaled hazard rate reductions.

Net Present Value (£millions)	Central		Typical low		Typical High	
	No lag	40 yr lag	No lag	40 yr lag	No lag	40 yr lag
Measure A	763	64	(216)	(352)	1876	538
Measure A2	444	(307)	(610)	(755)	1641	202
Measure B	467	(452)	(796)	(990)	1901	158
Measure C	909	129	(218)	(368)	2179	693
Measure C2	560	(261)	(616)	(777)	1897	324
Measure D2	(93)	(97)	–	–	–	–
Measure E	110	62	44	34	185	94
Measure J	(149)	(179)	(188)	(195)	(105)	(160)
Measure K2	(142)	(233)	(264)	(285)	(3)	(174)
Measure L	52	16	2	(5)	108	39
Measure N	559	238	98	41	1084	461
Measure O	958	167	(183)	(337)	2253	740
Measure P	955	143	(216)	(374)	2285	731
Measure Q	1008	184	(181)	(342)	2360	780
Measure R	1148	6	(490)	(706)	3005	813

Measure D2 was calculated using non-linear scaling and a sequential life table run, though NPVs for the typical low and typical high hazard rates have not been determined. See section 5.3.3.17 on sequential modelling.

72. As can be seen in table 5.1a and 5.1b the net benefit for each measure for the 'typical high' sensitivity increases substantially. For Measures A2 (Euro revised), C2 (Early Euro revised), B (Euro high), H1, H2 and H3 (Retrofit) and K1 (LCP), the lower bound of the NPV using the 0.6% hazard rate reduction is negative but switches to positive using the 1.2% hazard rate reduction. For Measures G1, G2 (LEZ), I (Domcom coal) and K2 (LCP) (linear scaling only), the upper bound of NPV becomes positive, although the lower bound remains negative. For all other measures, the effect is not so great as to switch any of the overall net present values i.e. the NPV that were previously negative using the 0.6% hazard rate, remain negative using the 1.2% hazard rate.[20]

[20] As H1, H2 and H3 only just switch to positive for the 12% coefficient using linear scaling, it is possible that this switch would not occur using non-linear scaling.

73. The net benefit for each measure for the 'typical low' sensitivity decreases. For Measures A, C, O, P, Q and R, the NPV switches from positive using the 0.6% hazard rate reduction to negative using the 0.1% hazard rate reduction. For Measures A, A2, B, C, C2, H2, H3, O, P, Q and R the upper bound of the NPV using the 0.6% hazard rate reduction is positive but switches to negative using the 0.1% hazard rate reduction. For measure L, the lower bound of the NPV switches from positive to negative but the upper bound remains positive. For all other measures, the NPV (either positive or negative) remains unchanged

74. For those measures that were analysed using non-linear scaling, there was no change in whether the NPVs were positive or negative for the 6% or 1% coefficient or, for most measures, for the 12% coefficient. For measure K2, the upper bound NPV for the 12% coefficient was just positive using linear scaling but just negative using the more precise non-linear scaling.

5.3.3.8 Assume only primary particles have a long term effect

75. The cohort study used to derive the percentage hazard rate reductions found associations with both the $PM_{2.5}$ mixture in general and with sulphates specifically. Nonetheless, there is a view, particularly from toxicology studies, that within the general $PM_{2.5}$ mixture, primary particles are relatively more toxic (per $\mu g.m^{-3}$), and secondary particles (sulphates, nitrates) relatively less toxic, than the mixture as a whole. Whether or not secondary particles are likely to have effects is a key question that was considered for the forthcoming update of the COMEAP quantification report. In its interim statement (Department of Health 2006b), COMEAP considered that, in the absence of clear evidence to the contrary, the coefficient should apply equally to all components of $PM_{2.5}$, including sulphate. This will be covered in more detail in their full report. A sensitivity analysis has been performed on Measures O, P, Q and R to disaggregate the overall $PM_{2.5}$ mixture, to illustrate what would happen to the results if there were evidence for different effects of different components. The same mortality hazard rate has been used for each of the three fractions (primary particles, sulphates, nitrates), i.e. the analysis does not try to quantify different toxicities for these fractions. However it does show whether the overall effects on mortality have been estimated as arising from primary particles, sulphates, or nitrates. If the toxicological hypothesis is true, the mortality effects may be under-estimated in measures which lead preferentially to changes in primary particles, and over-estimated in measures that lead preferentially to changes in secondary particles. However, the view that sulphates and nitrates may be less toxic, is based on the effects of individual sulphate or nitrate compounds. In practice, sulphate or nitrate may condense onto other particles containing heavy metals, for example. The toxic behaviour of such mixed particles is unclear as the components may interact with each other. This issue deserves more study.

76. The results of the separate calculations for primary and secondary particles for the combined measures O, P, Q and R are given in Table 5.2 below. The results for O, P and Q show that sulphates make the smallest contribution of the three categories (none for Measure O which is a combination of transport measures only). For these measures, nitrates contribute about half of the life years contributed by primary particles. Thus, for these measures, primary particles are providing the highest proportion of the impact and the proportion would be even higher if it were the case

that primary particles were more toxic. Thus, for the combined measures O, P and Q, this sensitivity analysis suggests that the absence of an effect of secondary particles would be unlikely to cause a substantial underestimate of the benefits. For R, primary and secondary particles are contributing approximately equal numbers of lifeyears – if primary particles are more toxic and secondary particles less toxic, then the net result would probably still be similar to the result assuming all particles have similar toxicity. This conclusion however, might be different for some other measures, such as N, where secondary particles form a very high proportion of the total change in particle concentrations. These issues are still quite uncertain but the analysis gives an indication of the importance of future research to determine (if possible) which categories of particles are most important.

Table 5.2: Partitioning results by nitrate, sulphate and primary particles

Life years saved ('000s)	Nitrates		Sulphates		Primary	
	No lag	40 yr lag	No lag	40 yr lag	No lag	40 yr lag
Measure O	510 (20%)	272 (20%)	–	–	2,076 (80%)	1,117 (80%)
Measure P	549 (21%)	293 (21%)	46 (2%)	24 (2%)	2,066 (77%)	1,111 (77%)
Measure Q	588 (22%)	313 (22%)	46 (2%)	24 (2%)	2,070 (76%)	1,113 (76%)
Measure R	875 (23%)	465 (23%)	913 (24%)	485 (24%)	2,017 (53%)	1,071 (53%)

77. When only primary particles are included in the valuation, the impact on the chronic mortality values is proportionate to the impact on the life years. In terms of the effect on NPVs, they are lower but of the same sign as when secondary particles are included. As described above, omitting the secondary particles without changing the primary particle hazard rate is likely to overestimate the impact of this sensitivity i.e. it is likely that, if secondary particles are less toxic than $PM_{2.5}$ in total, then primary particles must be more toxic to give the same overall effect of $PM_{2.5}$. This would increase the benefits from primary particles as well as decrease the benefits from secondary particles. This is likely to be particularly important for transport measures.

5.3.3.9 Use direct $PM_{2.5}$ modelling for long term effects of particles

78. In the main analysis, PM_{10} modelling was used and the change in PM_{10} concentrations was taken to be equivalent to a change in $PM_{2.5}$. (This is because the policies considered generally address fine rather than coarse components of PM_{10}.) There is, of course, the question of whether the answer would differ if $PM_{2.5}$ was modelled directly. $PM_{2.5}$ modelling is much more uncertain but some modelling has been done and the results

were used in a sensitivity analysis of the life years saved under Measures Q and R.[21] The resulting health benefits are shown in Table 5.3 below.

Table 5.3: Health benefits from $PM_{2.5}$ and PM_{10} modelling

Life years saved ('000s)	$PM_{2.5}$		PM_{10}	
	No lag	40 yr lag	No lag	40 yr lag
Measure Q	1,643	861	2,626	1,376
Measure R	2,686	1,407	3,745	1,962

79. The results with direct $PM_{2.5}$ modelling are smaller by just under a third. In terms of the NPV effects, this does not have the effect of switching the results i.e. the calculations are lower but of the same sign as when PM_{10} results are used. The lower results are probably primarily providing an indication of the uncertainty in the $PM_{2.5}$ modelling rather than suggesting that the results based on PM_{10} modelling should be changed. This suggests that the approach in the main analysis of using the change in well modelled PM_{10} data to represent $PM_{2.5}$ is probably the most appropriate one at present.

5.3.3.10 Changes to lifetable methodology for long term effects of particles

80. The previous three sections (different hazard rate reduction, different components of particles and $PM_{2.5}$ modelling) have all used the same method of lifetable modelling as that in the main section. Sections 5.3.3.11 – 5.3.3.18 discuss the impact of changes to the lifetable methodology.

5.3.3.11 Adjust long term effects of particles for subject's level of education

81. The Health Effects Institute reanalysis (HEI, 2000) found that, if the population was stratified into groups with less than high school, high school and more than high school education, then the risk was confined to those with high school education or less. The risk was lower and was not statistically significant in those with more than high school education. This raises the issue of whether such a stratification should be performed for quantification in the UK. However, it is uncertain how US educational status translates to a UK equivalent. Such an analysis has not been performed here but it should be noted that (i) people of lower educational status were under-represented in the US American Cancer Society cohort and so, if the effect is real, a more representative cohort might have given rise to higher risk estimates; and (ii) pollution reductions in deprived areas may result in greater health benefits than elsewhere.

[21] Combined Measures Q and R include either Measure C or C2 i.e. early incentivisation of Euro standards. The PM_{10} modelling used in the central analysis includes the incremental impact of this measure in the short term by taking the difference between Measure A and Measure C or between Measure A2 and C2 (for measure R) over a 20 year period. This 20 year analysis was not possible for the $PM_{2.5}$ modelling. Therefore for comparative purposes, it has also been omitted from the PM_{10} results within this section to ensure a like-for-like comparison.

5.3.3.12 Apply reduction in hazard rate for long term effects of particles to those under 30

82. The US cohort study used to derive the percentage reductions in hazard rates, only studied subjects over 30. Therefore the lifetable analysis only applies the hazard rate reductions to people over 30. This is what is conventionally done in impact estimation. There is however evidence from time series studies of children up to age 5, and from one cohort study of infants, that air pollution increases risks of mortality in the very young; and it is certainly plausible that those aged 5-29 years are affected also. Applying the hazard rate reductions to those under 30 would increase the size of the benefits by a small amount. This is unlikely to make a marked difference to the conclusions since mortality rates are very low in the under 30s.

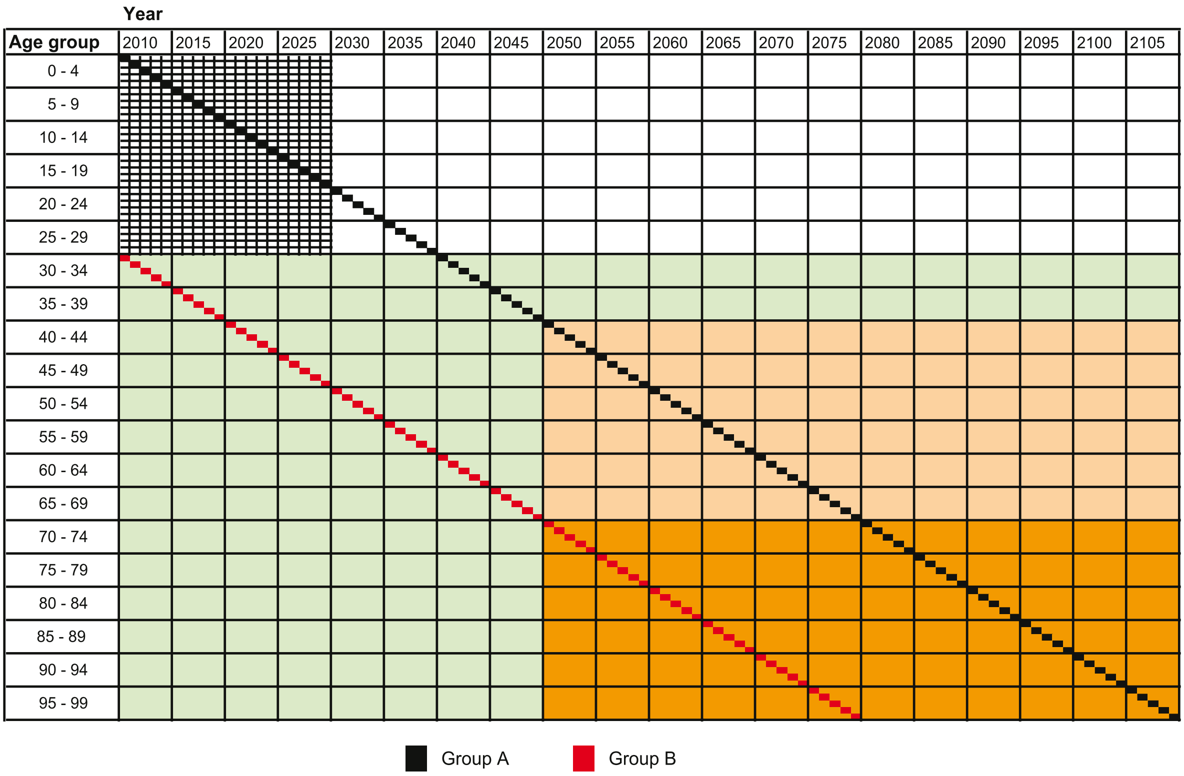
5.3.3.13 Assume long term exposure to particles at different times of life is important[22]

83. The methodology used for the 40 year lag assumes that if, for example, there was a 1 year reduction in 2010, then there would be an effect 40 years later on people born in 2010. The main cohort studies such as the ACS study give no specific evidence that supports exposure in the first year of life contributing to later effects on mortality but no evidence against it either. A cohort study of mortality in infants shows that some very young people are affected more-or-less immediately (Woodruff et al, 1997). Among adults, the ACS study only studied people over 30 in terms of collecting health data and recording deaths and there is no information one way or the other as to their exposure to pollution earlier in life. It can safely be assumed that they were exposed throughout their lifetime but the level of the earlier exposure is unknown. For the majority it will have been higher than during the follow-up itself, given the decline over time in PM concentrations across the USA. It is also unknown whether this earlier exposure had an influence on the fact that people died earlier in more polluted cities. The way in which the lifetable methods were implemented in the main analysis assumes that such earlier exposure could affect later mortality. If this was not the case then the answer would be smaller. If, for example, exposure had no effect until people were aged 30 or above, then, for the 40 year lag, a reduction in mortality rate would only apply to people who had been aged 30 or above in 2010 and were aged 70 or above 40 years later. This is a much smaller proportion of the population than those aged 40 or above 40 years later as is used for the 40 year lag in the main analysis (assuming exposure from birth can affect later mortality). See Figure 5.2. The effect on life years would not be as marked as a proportion of the population affected (as mortality rates are much higher in the elderly) but the result would still be smaller. Much more research is needed on the relevant 'windows of exposure' before this issue can be resolved.

[22] When thinking about this issue it is important to distinguish (i) the age or the time when a hazard rate reduction is applied in the lifetables (or, put another way, the age or the time when a change in mortality is apparent) from (ii) the age or the time at which exposure matters (even if the change in mortality does not occur until later). Some mechanisms might not be relevant in young children, for example.

Figure 5.2

Different assumptions regarding the time of life at which exposure is important (sustained exposure, 100 years)



Consider two groups . As shown by examining the finely divided squares, Group A includes people born in 2010 age 10 in 2020, 20 in 2030 etc. Group B includes people age 30 in 2010, 40 in 2020, 50 in 2030 etc. Suppose there is no lag but changes in mortality rates are not apparent in 2010 in those under 30. Changes in mortality rate will be apparent in 2010 in Group B but not Group A. However, by 2040, those born in 2010 are over 30, the changes in mortality rate will apply in Group A as well. For the population as a whole, the proportion of the population over the 100 years experiencing changes in mortality is represented by the green shaded area, plus the light orange area and dark orange areas. By coincidence, this shaded area also represents the situation where exposure only has an effect in those over 30 and there is no lag.

However, for a 40 year lag, there is a distinction. If exposure from birth affects later mortality rates, then Group A will experience changes in mortality rates from age 40 in 2050. For the population as a whole, the proportion of the population experiencing changes in mortality is represented by the light orange and dark orange areas. In contrast, if exposure below 30 has no effect on mortality rates even at a later stage then exposure in 2010-2019 will only affect Group B, with the effect becoming apparent in 2050. Group A will only be affected by exposure in 2040-2049 when over 30, with the effect not becoming apparent until 40 years later in 2080 when the group have reached the age of 70. For the population as a whole, changes in the mortality rate will only be apparent in the dark orange area. As the dark orange area is smaller than the dark orange area plus that light orange area, the effect on life years will be smaller if exposure below 30 has no effect even at a later stage.

5.3.3.14 Assume underlying mortality rates do not remain constant

84. The main analysis assumes that the baseline mortality rates remain constant, i.e. the different percentage reductions in hazard rate due to reductions in pollution are applied to the same mortality rate in each age group throughout the 100 year follow-

up. In fact, people are expected to live longer on average in the future.[23] This would, potentially, increase the total life years gained. At higher levels of pollution people dying at a particular age are likely to be foregoing a longer remaining life expectancy on average, conversely this longer remaining life expectancy is likely to be gained if pollution is reduced. However, this effect is thought to be small in the context of the overall lifetable. Work by others has suggested that the gains in life years are relatively insensitive to baseline mortality rates.[24] In addition, when the gains in life years are calculated separately for males and females, the answers are quite similar, despite the different underlying mortality rates and life expectancies for males and females.

5.3.3.15 Assume a different lag time for long term effects of particles

85. As mentioned in Chapter 2, section 2.5.3.10, the main analysis has used a range for the lag between 0 and 40 years. This is based on the recommendation in the COMEAP report on long term exposure to particles in 2001. This, in turn, was based on the fact that in the ACS study (HEI, 2000) relative risks were similar in the over and under 50s – if a lag time longer than 40 years or so was required then an increased risk in the under 50s would not be expected. This is rather weak and indirect evidence. There is a lack of direct evidence on this question although some groups have judged that a higher proportion of the effect may involve shorter lags.[25]

86. The time series studies show that, at least in some of the earlier deaths, the lag time can be less than a week i.e. an immediate effect. This is likely to be only a small component of the total effect captured by the cohort studies. Distributed lag studies (time series studies covering exposure over multiple days, up to about 6 weeks) show higher coefficients than 'ordinary' time series studies. Intervention studies (e.g. the drop in mortality over a 6 year period following a ban in coal sales in Dublin, Clancy et al (2002)) show substantial changes in mortality risks with relatively short delays after exposure e.g. in the subsequent five years. On the other hand, lung cancer mortality is one of the types of mortality affected by long term exposure to particles,[26] and lung cancer can take decades to develop. However, lung cancer is less common than cardiovascular disease, and cardiovascular mortality is the most important effect of long term exposure to particles. There is more information than there was when COMEAP came to its conclusions in 2001. In a recent interim statement (Department of Health, 2006b), although the evidence was still considered limited, COMEAP's judgement tended towards a greater proportion of the effect occurring in the years soon after pollution reduction rather than later. In its full report (Department of Health, 2007), COMEAP noted that, based on the Dublin study, it seemed likely that a noteworthy proportion of the effect was likely to occur within the first 5 years.

87. In the meantime, the possibility that lags substantially shorter than 40 years may predominate, is noted. This is within the range of 0 to 40 years analysed but could substantially lessen the weight given to the 40 year end of the range. For the policy scenarios where pollution reductions are sustained for longer periods this would tend

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[23] See: http://www.gad.gov.uk/Life_Tables/Period_and_cohort_eol.htm

[24] IOM, 2000; Leksell and Rabl (2001). Note, the relative insensitivity of gains in life years to baseline mortality rates may not apply when these are very different, eg, in a place with high infant mortality rates.

[25] See http://www.epa.gov/sab/pdf/council_ltr_05_001.pdf

[26] The exact role of air pollution as an initiator or promoter of lung cancer is unclear.

towards a larger result. This could make a substantial difference as the no lag result is around twice as large as the 40 year lag result. For the policy scenarios with shorter durations, the opposite would be the case.[27] Further analysis on the effect of lag times on benefit results is discussed in section 5.6 below.

5.3.3.16 No cut-off in 2109 for calculations of long term effects of particles

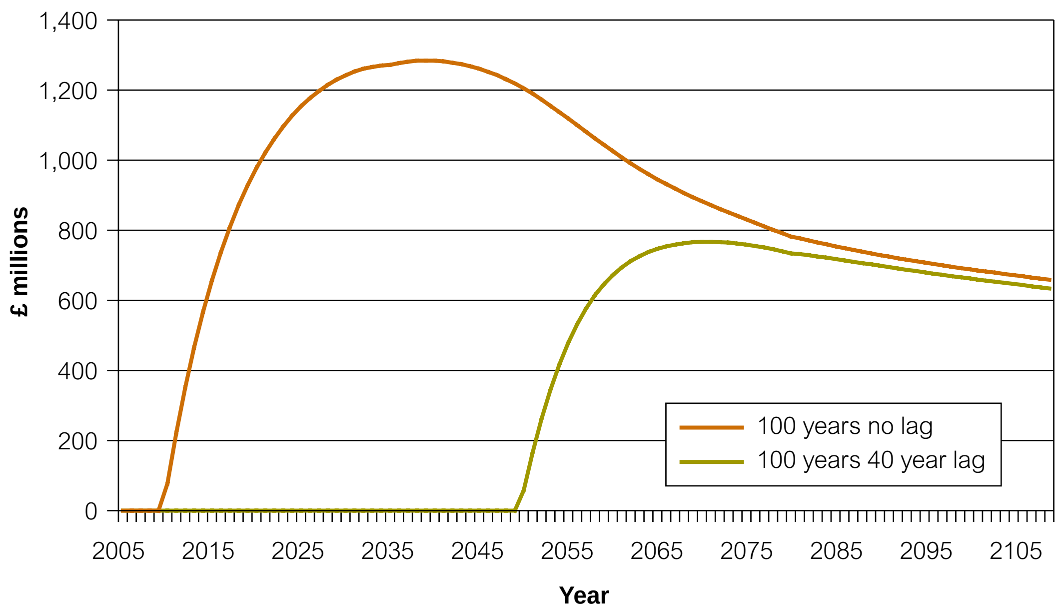
88. The main analysis followed the lifetable to 2109. This time period was chosen to represent the lifetime of the population alive at the start in 2010. However, as new cohorts are added each year, the benefits are likely to extend beyond 2109.

89. As explained in Chapter 2, the monetised health impacts are uplifted by 2% and then discounted using the discount rates recommended by the HM Treasury Green Book. Due to the presence of the uplift factor, future benefits of the measures are valued relatively more highly compared to the costs. This is more manifest when the time period over which costs and benefits are considered is extended, taking into account declining discount rates. Figure 5.3 shows that the valuations of the health impacts plateau after 2109 and do not approach zero.

90. Therefore the cut off in 2109 will underestimate the benefits as well as the costs of the policy. However, taking into account the uplift factor, the benefits of the policy will be significantly more underestimated relative to the costs.

Figure 5.3

Value of 100 year standard life table runs (England and Wales only)



[27] This is related to the fact that populations in the future are expected to have higher proportions of the elderly and therefore higher baseline mortality rates. A percentage reduction in these rates will give a greater gain in life years. This effect has greater proportional influence for short durations of effect (see paragraph 166 in Chapter 2 for further explanation).

5.3.3.17 Incorporate sequential concentration changes in calculations of long term effects of particles

91. The main analysis used a simplified concentration change scenario where, for the long term measures, the 2020 concentration reduction was assumed to apply from 2010 for 100 years. The result was scaled from a total life years result from a standard 1% hazard rate reduction for 100 years. In fact, the true situation is more complicated. There is a baseline (agreed measures) that itself includes several stepwise concentration reductions starting from 2005. The additional measures also contain stepwise concentration reductions. These results need to be compared with each other. To take into account these different sequential changes, individual lifetable runs need to be done for the baseline and each measure for no lag and a 40 year lag. This is a more accurate way to do the analysis and is recommended for future cost benefit analysis. For this analysis, due to time constraints, this was not done for all the measures. However, representative measures were chosen to illustrate the degree of approximation provided by the simplified concentration change approach.

92. The measures chosen were Measure B (Euro high), Measure D (Phase out), Measure J (Domcom NO_X) and Measure R (combined). Measure B was chosen because it has one of the largest concentration reductions of the individual measures[28] that is maintained long term. Measure J is also long term but is a domestic rather than transport measure. Measure D is a short term measure. Measure R is a combined measure of Measures C2 (Early Euro revised), E (LEV) and N (Shipping). It was predicted that the sequential change result would differ more from the simplified concentration change result for larger concentration reductions and for larger percentage hazard rate reductions. This was because the larger the reduction in mortality in one year, the more it changes the age distribution of the population in the following year and so on as the years go on. This ongoing change in age distribution is only taken into account for one concentration reduction in the simplified concentration change approach rather than several. The 0.6% reduction in hazard rate per $\mu g.m^{-3}$ $PM_{2.5}$, was used for these calculations.

93. The concentration changes for the various measures examined are shown in Tables 5.4 and 5.5 below. The corresponding hazard rate changes obtained by non-linear scaling (see footnote 66 of Chapter 2) of the $\mu g.m^{-3}$ concentration changes are also shown. Note that the short term Measure D reverts to a concentration reduction identical to that for the baseline (agreed measures).

[28] Measure B does not have the largest concentration reduction in 2010 but it does in 2020 which is most important for the final result since the 2020 concentration reduction is maintained until 2109.

Table 5.4: Concentration changes and hazard rate reduction for sequential concentration change calculations – long term measures

		2003	2005	2010	2015	2020
Baseline (agreed measures)	PM_{10} concentration µg.m^{-3}	22.424	21.554	19.880	19.084	18.543
	Absolute change in concentration from 2003 baseline	0.000	–0.870	–2.544	–3.340	–3.881
	% drop in hazard rate at 0.6% relative to 2003 baseline	**0.000**	**–0.506**	**–1.471**	**–1.927.**	**–2.236**
Measure B (Euro, High Scenario)	PM_{10} concentration µg.m^{-3}	22.424	21.554	19.812	18.634	17.797
	Absolute change in concentration from 2003 baseline	0.000	-0.870	-2.612	-3.790	-4.627
	% drop in hazard rate at 0.6% relative to 2003 baseline	**0.000**	**-0.506**	**-1.510**	**-2.184**	**-2.660**
Measure J (Domestic Combustion Product Standards)	PM_{10} concentration µg.m^{-3}	22.424	21.554	19.874	19.064	18.521
	Absolute change in concentration from 2003 baseline	0.000	-0.870	-2.551	-3.360	-3.904
	% drop in hazard rate at 0.6% relative to 2003 baseline	**0.000**	**-0.506**	**-1.475**	**-1.939**	**-2.249**
Measure R (Combined Early Euro revised, LEV and Shipping)	PM_{10} concentration µg.m^{-3}	22.424	21.554	19.592	18.424	17.617
	Absolute change in concentration from 2003 baseline	0.000	-0.870	-2.832	-4.001	-4.807
	% drop in hazard rate at 0.6% relative to 2003 baseline	**0.000**	**-0.506**	**-1.637**	**-2.304**	**-2.762**

Table 5.5: Concentration changes and hazard rate reduction for sequential concentration change calculations – short term measure

		2003	2005	2010	2015	2020
Baseline (agreed measures)	PM_{10} concentration µg.m^{-3}	22.424	21.554	19.880	19.084	18.543
	Absolute change in concentration from 2003 baseline	0.000	–0.870	–2.544	–3.340	–3.881
	% drop in hazard rate at 0.6% relative to 2003 baseline	0.000	–0.506	–1.471	–1.927	–2.236
Measure D2 (Phase out)	PM10 concentration µg.m^{-3}	22.424	21.554	19.859	19.073	18.543
	Absolute change in concentration from 2003 baseline	0.000	-0.870	-2.565	-3.351	-3.881
	% drop in hazard rate at 0.6% relative to 2003 baseline	0.000	-0.506	-1.483	-1.934	-2.236

94. The hazard rate reductions were incorporated into a lifetable run and followed up until 2109. The total life year results for the baseline (agreed measures) were then subtracted from the total life year results for the measures and the difference multiplied by 1.128 to scale up from the England and Wales to the UK population. The results are shown in Table 5.6. The simplified concentration change results are also shown for comparison (calculated as for the main analysis).

Table 5.6: Life years saved for simplified concentration change method and sequential change method with non linear scaling – short and long term measures

Life years saved (United Kingdom) (000's)			
	Simplified concentration change method	**Sequential change method**	**% difference[a]**
Long term measures (2010 – 2109)			
Measure B (zero lag)	3,017	2,716	11%
Measure B (40 year lag)	1,581	1,319	20%
Measure J (zero lag)	92	82	11%
Measure J (40 year lag)	48	41	16%
Measure R (zero lag)	3,805	3,435	10%
Measure R (40 year lag)	2,020	1,703	19%
Short term measure[b] (2010 – 2019)			
Measure D2 (zero lag)	4	7	(33%)
Measure D2 (40 year lag)	5	7	(31%)

[a] Simplified minus sequential divided by sequential result calculated before rounding.
[b] Simplified change method uses 5 year sustained standard factor.

95. For the long term measures, it can be seen that the simplified concentration change method used in the main analysis, overestimates the benefits. The overestimate increases with increasing size of hazard rate reduction up to a maximum of 11% (no lag) or 20% (40 year lag) for Measure B (the measure resulting in the largest concentration reduction). It must however be noted that this differential is a combination of two sensitivities – the incorporation of sequential changes and the use of non-linear scaling. The size of this overestimate will probably be less for the hazard rate reductions less than 0.6% per $\mu g.m^{-3}$ but greater for the hazard rate reductions above 0.6% per $\mu g.m^{-3}$. It can also be seen that the overestimate is usually greater in percentage terms (but not absolute terms) for the 40 year lag compared with no lag.[29]

[29] The probable reason is that the life years gained from the higher hazard rate reductions for the first 20 years in the simplified concentration change approach are a higher proportion of the total life years (summed over only 60 years for the 40 year lag) than for no lag (summed over 100 years).

96. Before the analysis started, the plan was to use a small number of standard factors for shorter sustained periods (5 years and 20 years), on the assumption that these would approximate the appropriate time periods for the short term measures. The calculation shown in the left hand column of Table 5.6 under short term measures was performed on this basis. This shows that, for the short term measures, the simplified concentration change approach underestimates the sequential concentration change result substantially. The major reason for this is that the short term measures do not in fact stop in 5 years (by 2015) but still show a slightly greater concentration reduction than the baseline from 2015 to 2019. Calculations were performed (not shown) using the 5 year sustained factor multiplied by the appropriate hazard rate reduction based on the 2015 concentration reduction and adding this to the calculation based on the 2010 concentration reduction. This brought the result much closer to the sequential change result (within 2% to 4%). But by the time the 'simplified' concentration change approach starts using multiple calculations with different concentration changes, it is more straightforward and more accurate to use the sequential concentration change result directly. This is what was in fact done for Measure D2 in the main analysis. Thus, the 'simplified' concentration change approach only provides a reasonable approximation if standard factors have been chosen that are a good match for the time period of the policy. The sequential concentration change approach uses the relevant time periods directly.

97. The impact in terms of valuation of the life years is shown in Table 5.7 below. For the long term measures, the effect on values is slightly greater than the effect on physical life years due to the combination of the uplift and discounting of the valuation of life years over time. For the short term measure, the valuation result looks slightly counter-intuitive compared to Table 5.6, i.e. the simplified concentration results in valued terms are greater than the sequential change method. This is because values are presented on an annualised basis; the simplified concentration results used a 5 year lifetable and were therefore annualised over a 5 year basis, the sequential results showed an effect over 10 years and have therefore been annualised over 10 years.

Table 5.7: Valuation of UK life years saved for simplified concentration change method and sequential change method – short and long term measures

Valuation of UK life years saved (£ million p.a.)			
	Simplified concentration change method	Sequential change method	% difference[a]
Long term measures			
Measure B (zero lag)	1,571	1,365	15%
Measure B (40 year lag)	669	543	23%
Measure J (zero lag)	48	42	14%
Measure J (40 year lag)	20	17	17%
Measure R (zero lag)	2,039	1,743	15%
Measure R (40 year lag)	886	707	20%
Short term measure			
Measure D2 (zero lag)	26	15	68%
Measure D2 (40 year lag)	18	11	71%

[a] Simplified minus sequential divided by sequential result.

98. Some possible reasons for the differences between the simplified concentration change and the sequential concentration approach are given in Table 5.8.

Table 5.8: Possible factors accounting for differences between the simplified concentration change and sequential concentration change approaches

Simplified concentration change	Sequential concentration change	Expected effect for simplified compared with sequential approach
Omits concentration changes in baseline 2005-2009[30] so starting population in 2010 unchanged.	Includes concentration changes in baseline 2005-2009 so starting population in 2010 is larger with an older age profile.	Less gain in life years.
Applies 2020 concentration reductions from 2010 to 2020.	Applies the actual smaller concentration reductions in 2010 and 2015.	More gain in life years[31].
Relies on standard factors being available that match the relevant time period for the policy.	Uses the relevant time period for the policy directly.	More or less gain in life years depending on how well the standard factor time period matches the relevant time period for the policy.
Applies linear scaling to the calculate life years lost.	Applies non-linear scaling to calculate life years lost.	More gain in life years.

5.3.3.18 Validity of 'annual pulse' approach

99. Measures D1 (Phase out), G1-3 (LEZ), H1-3 (Retrofit), I (Domcom coal) and K1 (LCP short term) only had emissions data available and were short term measures. In these cases, in the main analysis, 'annual pulse' damage costs per tonne were used. These assume that the modelled pollution change occurs for one year only. The 'annual pulse' is then multiplied up for the relevant number of years for the short term measure (5-15 years, depending on the measure). Because the modelled pollution change is for one year only, this approach does not take into account the carry-over of effects on age structure and size of population, that is included in lifetable runs using sustained reductions in concentrations. Some analysis was undertaken to check how large a difference this omission would make.

[30] The same gains in life years occurs from 2005–2009 in both the baseline and the measures so there is no additional gain for the measures when the difference from the baseline is calculated. But there are carry over effects – if deaths have been avoided in the years before 2010, the population will be larger with an older age profile. Applying the same hazard rate to a larger, older underlying population will give larger answers and will contribute to the difference between the simplified concentration change and sequential concentration change approach.

[31] This extra gain in life years results from both the extra life years generated from the extra concentration reductions from 2010 to 2020 and from the change in the size and age structure of the 2020 population as a result of these extra charges.

100. The comparison uses the 'standard factors' used for the main analysis (see section 2.5.3.12 in Chapter 2). The results comparing the annual pulse with both the 5 year and the 20 year sustained pollution reductions are presented in Table 5.9. The results are in terms of total years of life lost for the population of England and Wales.

Table 5.9: Comparison between multiples of annual pulse and sustained result

Life years (000's)	Sustained 5 years	Pulse 1 year	Pulse*5	Pulse*5 as % of sustained result
1% hazard reduction, no lag	312	61	307	98.5%
1% hazard reduction, 40 year lag	330	67	334	101.2%
	Sustained 20 years	**Pulse 1 year**	**Pulse*20**	**Pulse*20 as % of sustained result**
1% hazard reduction no lag	1,323	61	1,229	92.9%
1% hazard reduction, 40 year lag	1,268	67	1,336	105.3%

101. The discrepancy between the results from the annual pulse factored up by the appropriate number of years, and the results from the sustained reduction in hazard rates is less than 10% in these examples. In general, we would expect the discrepancy to increase both with the number of years that the annual pulse is being scaled by, and with the hazard rate.[32] The maximum reduction in hazard rates caused by changes in concentrations for any of the additional measures is 3%, which is more than the illustrative 1% used here but less than the 10% used in some other calculations (see footnote).

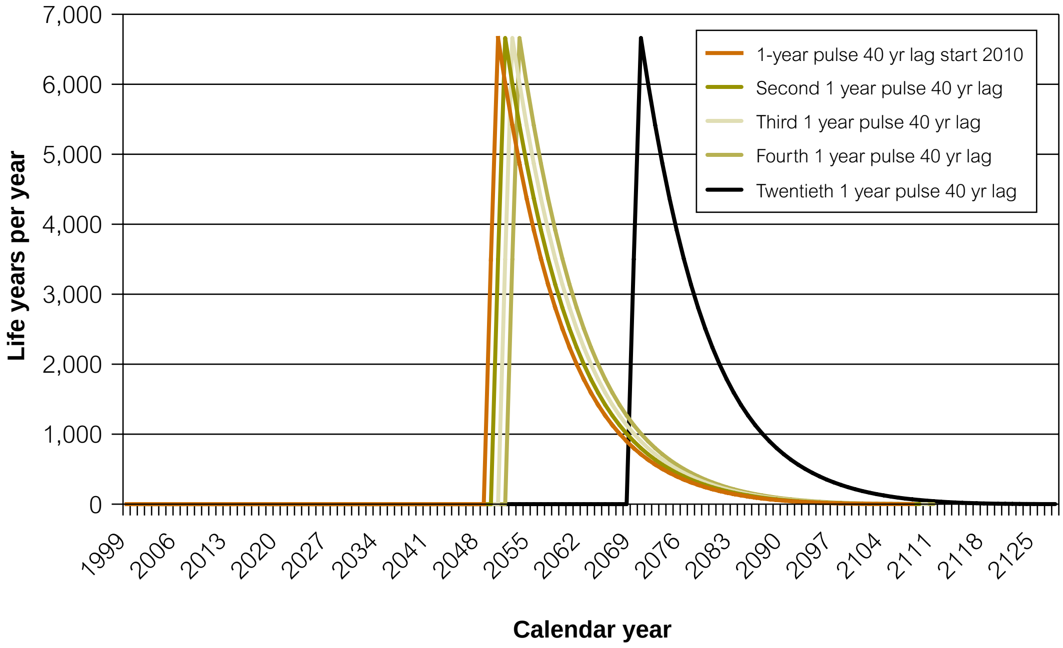
102. It is worth noting that, for longer durations, an additional point has to be considered. This is that each annual pulse is followed up for 100 years. This means that an annual pulse in 2011 will be followed to 2110, an annual pulse in 2012 will be followed to 2111 etc. In other words, the results extend beyond the 2109 cut-off used for the sustained pollution reduction calculations. For no lag and short durations, this effect does not matter as the lifeyears per year for the 2010 annual pulse no lag become negligible by 2077. But it probably accounts in part for the slight overestimate for the 40 year lag and short durations. Figure 5.4 shows that, for 20 times the annual pulse

[32] A calculation using a 10% hazard rate reduction and no lag for a slightly different scenario (starting in 2005 rather than 2010) showed the 'pulse times 20' result was 90.8% of the 20 year sustained result. This was a larger discrepancy than for the equivalent 1% hazard rate reduction.

for the 40 year lag, the extension beyond 2109 is becoming noticeable. For longer durations, multiples of the annual pulse will substantially overestimate a sustained result with a cut off in 2109.

Figure 5.4

Annual pulses compared to 2109 cut-off



103. The results have also been analysed in monetary terms, applying the agreed value of lifeyear, uplift factor and discount rate, assuming policies starting in 2010. The results have been annualised, consistent with the main analysis. A comparison of values for the 1% reduction in hazard rate are shown in Table 5.10 below.

Table 5.10: Comparison of valuations for multiples of annual pulse and sustained result

Value of life years £m p.a.	Sustained 5 years	Pulse 1 year	Pulse*5	Pulse*5 as % of sustained result
1% hazard reduction, no lag	1,566	1,483	1,433	92%
1% hazard reduction, 40 year lag	1,060	1,022	987	93%
	Sustained 20 years	**Pulse 1 year**	**Pulse*20**	**Pulse*20 as % of sustained result**
1% hazard reduction no lag	1,906	1,483	1,638	86%
1% hazard reduction, 40 year lag	1,209	1,022	1,128	93%

104. In summary, for the size of the pollution changes analysed in this document, and for policies of short duration, the annual pulse provides a reasonable approximation.

5.3.3.19 Inclusion of trans-boundary effects

105. The current cost benefit analysis has taken account of benefits that accrue within the UK both from improvements in air quality from the implementation of measures and, where applicable, from the implementation of measures throughout Europe. This is in line with the recommended practice for regulatory impact assessments. However, the implementation of policies in the UK would also lead to a reduction in trans-boundary pollution from the UK to Europe: UK policies may help to reduce the long-distance transport of PM_{10}, secondary pollution precursors and the formation of secondary PM_{10} and ozone, all of which would have associated health benefits in the rest of Europe.

106. The benefits of the measures considered in this Strategy in terms of a reduction in trans-boundary pollution to Europe (from emission reduction in the UK) have not been quantified or valued for all measures, but a sensitivity analysis has been undertaken on Measure Q to examine the potential impact. This has shown that including trans-boundary benefits would increase the economic benefits of Measure Q by 32%, over and above the UK benefits alone.[33]

[33] Trans-boundary analysis was undertaken using the 100% precursor to secondary particle response function. If the 50% response function was used, then the increased economic benefits of Measure Q would be expected to be reduced.

107. The impact of other measures will vary because of the split of different pollutants and because different pollutants are 'exported' in varying degrees.

5.3.4 Sensitivities around the values used to monetise the benefits

108. This section assesses sensitivities around the values used to monetise the benefits. The underlying values for this analysis have been published alongside the IGCB report and are available electronically at http://www.defra.gov.uk/environment/airquality/strategy/igcb/index.htm. The Monte Carlo analysis in Annex 7 also includes further analysis on the sensitivities around these monetary values.

5.3.4.1 Sensitivity on health valuation

109. The recommended sensitivities for the health values are shown in Table 2.9 in Chapter 2. The rationale for these sensitivities is explained below, followed by the results.

110. When considering the valuation of acute mortality, it is generally assumed that deaths are likely to occur in patients with severe pre-existing disease (Department of Health, 1998). For example, patients with chronic obstructive pulmonary disease are usually ill for some years prior to their death and have become increasingly seriously ill over time. However, for cardiovascular disease, it is known that some deaths occur suddenly in people who are apparently 'healthy' i.e. people who have a disease but no symptoms. There is therefore the possibility of gains in 'healthy' life expectancy occurring if these sudden deaths could be deferred. Trying to determine the proportion of the deaths brought forward by air pollution that could be attributed to this 'sudden cardiac death' category is extremely difficult and is discussed in more detail in Annex 2. On current evidence, it was estimated that 10% to 15% of all acute deaths might fall into this category. The sensitivity analysis therefore values 10%-15% of the mortality impacts using the value appropriate to those in good health (£29,000 in 2004 prices) as opposed to the value appropriate to those in poor health (£15,000 in 2004 prices). These values are based on the results of the Chilton et al (2004) study.

111. There are numerous uncertainties associated with the valuation of health effects, the main ones of which have been highlighted in paragraph 180 of Chapter 2. For the valuation of chronic effects, it was therefore recommended that a range should be used, reflecting the 95% confidence interval around the central value. This is used in an attempt to reflect some of the uncertainties but by no means captures all of them. The range used is £21,700-£36,200 (2004 prices).

112. The central values for morbidity take account of both resource costs and 'disutility'. Resource costs include medical costs incurred by the health services, such as time spent by GPs and the cost of drugs, and private costs of dealing with illness, such as travelling to see a doctor. The disutility costs reflect the wider disutility of ill-health both to the individual and his/her family and friends; it is sometimes referred to as 'pain, grief and suffering'. In addition to these costs, there is the possibility of further costs in terms of opportunity costs i.e. the cost in terms of lost productivity and the opportunity cost of leisure including non-paid work. EAHEAP noted that the loss in work output due to air pollution induced morbidity is likely to be negligible as the

elderly and seriously ill will be most affected,[34] of which the vast majority are expected to be above retirement age anyway. However, opportunity costs have been included in certain analyses of air pollution effects, e.g. in the recent impact assessment for CAFE and was recommended for sensitivity analysis. A value of £62 per day (2004) is used based on a survey carried out by the Confederation of British Industry and reported in the 'Methodology for the Cost-Benefit Analysis for CAFE: Volume 2: Health Impact Assessment'.[35] The effect of this sensitivity is to increase the upper value for respiratory hospital admissions by £496 (2004 prices, based on an average stay of 8 days) and the upper value for cardiovascular hospital admissions by £558 (2004 prices, based on an average stay of 9 days).

113. Sensitivity analysis using the recommended ranges has been undertaken. Rather than assessing the impact of the values on an individual basis, the overall impact of the valuation sensitivities has been considered i.e. applying the lowest sensitivity values to the low end of the NPV ranges and the highest sensitivity values to the high end of the NPV ranges.

114. The sensitivity analysis extends the ranges of the NPV although based on a 0.6% hazard rate per $\mu g.m^{-3}$ it does not alter the conclusions as to which measures are considered favourable on a cost benefit basis.

5.3.4.2 Social cost of carbon

115. The current guidance on the social cost of carbon suggests the use of a range of £35-£140/tonne (2000 prices) as sensitivity. This guidance also recommends increasing these estimates by £1/tonne (2000 prices) each year. The sensitivity analysis undertaken here follows these recommendations, having adjusted the social cost of carbon to 2005 prices to ensure consistency with the other monetised benefits.

116. It has not been possible to estimate the carbon impacts for all measures. For those that have been estimated, the measures relating to Euro Standards (Measures A, A2, B, C and C2), K1 (SCP short term), K2 (SCP long term) and P (combined measure) increase the tonnes of carbon emitted. Therefore using the lower bound of the sensitivity range improves the net present value; using the upper bound of the sensitivity analysis has a negative effect on the overall net present value. Measures D1 (Phase out), D2 (Phase out), E (LEV), I (Domcom coal) and O, Q and R (combined measures) have a positive impact on carbon emissions (i.e. reduces the amount emitted). Using the lower bound of the sensitivity analysis therefore worsens the net present value; using the upper bound improves it.

5.3.5 Conclusions regarding benefits sensitivities

117. This section on benefit uncertainties and sensitivity analysis has incorporated many possible different effects. As with the uncertainty analysis regarding modelling presented in section 5.2, it is not practical to combine all the uncertainties and sensitivities relating the quantification and valuation of benefits to arrive at an estimate

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[34] This point may not apply to all morbidity effects e.g. respiratory symptoms can probably affect all ages.

[35] Hurley et al (2005) 'Methodology (Volume 2) for Service Contract for Carrying out Cost-Benefit Analysis of Air Quality Related Issues, in Particular in the Clean Air for Europe (CAFE) programme'. Available at: http://europa.eu.int/comm/environment/air/café/activities/cba.htm, http://www.café-cba.org

of total uncertainty, although a combination of selected uncertainties has been assessed as part of the Monte Carlo analysis presented in section 5.6 of this chapter.

118. The main quantified sensitivities that could be taken into account, however, include:

- *No long term effect of particles:* It is possible that some unknown confounders could account for the apparent effect of long term exposure to particles on mortality. This is becoming increasingly unlikely as a wider range of studies of the effect of long term exposure to particles are published. Nonetheless, this unlikely possibility, has been considered as part of the sensitivity analysis to illustrate that some effects on mortality would still be quantified. The assumption that there are no chronic mortality effects from particles has a major impact on the cost benefit results. For all measures, except Measure E (LEVs) and N (Shipping), the annual net present value is negative i.e. the measures are no longer justifiable in cost benefit terms. Even the shipping measure is only marginally beneficial (annual NPV from £1-3m).
- *Other coefficients for long term effect of particles, in addition to the hazard rates considered in the main analysis:* The recent COMEAP report (Department of Health, 2007), has suggested 'typical low' and 'typical high' sensitivities of a 0.1% and 1.2% hazard rate reduction per µg.m^{-3} $PM_{2.5}$. These alternative reductions in hazard rate per µg.m^{-3} $PM_{2.5}$ are shown to change the chronic mortality in what approximates a linear manner i.e. the chronic mortality values are twice as large as the values when assuming a 1.2 % hazard rate reduction per µg.m^{-3} $PM_{2.5}$ as the values when assuming a 0.6% per µg.m^{-3} hazard rate reduction and a sixth smaller when using a 0.1% hazard rate reduction[36]. Notable implications include:
  - For Measures A2 (Euro revised), B (Euro high), C2 (Early Euro revised), H1, H2 and H3 (Retrofit) the lower bound of the NPV using the 0.6% per µg.m^{-3} hazard rate reduction is negative but switches to positive using the 1.2% per µg.m^{-3} hazard rate reduction.
  - For Measures A, C, O, P, Q and R, the NPV switches from positive using the 0.6% hazard rate reduction to negative using the 0.1% hazard rate reduction at the upper bound. For A2, C2, H2, H3 and K1 the upper bound switches from positive to negative with the lower bound remaining negative and for L the lower bound switches from positive to negative with the upper bound remaining positive.
- *Lack of an effect of secondary particles:* The cohort study used to derive the percentage hazard rate reductions found associations with both the $PM_{2.5}$ mixture in general and with sulphates specifically. Nonetheless, there is a view, particularly from toxicology studies, that within the general $PM_{2.5}$ mixture, primary particles are relatively more toxic (per µg.m^{-3}), and secondary particles (sulphates, nitrates) relatively less toxic, than the mixture as a whole. A sensitivity analysis has therefore been performed on the combined measures O, P, Q and R to disaggregate the overall $PM_{2.5}$ mixture. The same hazard rate has been used for each of the three fractions (primary particles, sulphates, nitrates); i.e. the analysis does not try to quantify different toxicities for these fractions. The results show that for measures O, P and Q sulphates make the smallest contribution of the three categories (none

[36] Linear scaling is a reasonable approximation for the small coefficients and small concentration changes used in most of the analysis in this report. The more precise equation used to quantify the impact of these different hazard rates is new RR = original study $RR^{newconcchange/origconcchange}$ where original study RR (relative risk) is 1.06 for an original concentration change of 10 µg/m3 and the new concentration change is the change in population weighted mean for the policy of interest. The new RR derived was then, as a percentage change, multiplied by the standard factor to give the desired result.

for Measure O which is a combination of transport measures only) and nitrates contribute about half of the life years contributed by primary particles. Thus, for these measures, primary particles are providing the highest proportion of the impact and the proportion would be even higher if it were the case that primary particles toxic. For R, primary and secondary particles make roughly equal contributions to the life years – an increased toxicity for primary particles and a decreased toxicity for secondary particles is likely to give the same net result as assuming an average toxicity for both. This sensitivity analysis suggests that the absence of an effect of secondary particles would be unlikely to cause a substantial underestimate of the benefits for these combined measures.

- *Inclusion of sequential concentration changes:* The main analysis uses a simplified concentration change scenario where, for the long term measures, the 2020 concentration reduction was assumed to apply from 2010 for 100 years. In fact, the true situation is more complicated. There is a baseline (agreed measures) that itself includes several stepwise concentration reductions starting from 2005. The additional measures also contain stepwise concentration reductions. When these results are compared with each other, using a 0.6% per $\mu g.m^{-3}$ hazard rate reduction, analysis shows that for the long term measures, the simplified concentration change method used in the main analysis, overestimates the health impacts somewhat. The overestimate increases with increasing size of hazard rate reduction up to a maximum of 11% (no lag) or 20% (40 year lag) for Measure B (the measure resulting in the largest concentration reduction).
- *Shorter lag times between exposure and effect:* The main analysis uses a range in lag times between 0 and 40 years. The 2006 COMEAP statement states that, although evidence was limited, the Committee's judgement tended towards a greater proportion of the effect occurring in the years soon after a pollution reduction rather than later (Department of Health, 2006b). This would mean the effect is more likely to be nearer the no lag result i.e. larger. The no lag result is approximately twice as large as the 40 year lag result so an emphasis on shorter lag times can have a marked effect on the results. Focusing on the net present value results assuming a 0.6% per $\mu g.m^{-3}$ hazard rate, A2 (Euro low revised), B (Euro high), C2 (Early Euro low revised), H3 (Retrofit) and K1 (SCP) have a negative NPV assuming a 40 year lag, but a positive NPV assuming a zero year lag. Therefore, taking account of the Committee's recent views on the lag effect might alter the conclusions drawn.
- *Inclusion of trans-boundary effects:* The main analysis takes account of benefits to the UK from the implementation of measures in the UK and, for Europe-wide measures, from the implementation of measures in other Member States. It does not, however, take account of benefits in the rest of Europe, in the form of trans-boundary effects, from the implementation of measures in the UK. A sensitivity analysis has been undertaken on Measure Q which shows that including trans-boundary benefits would increase the economic benefits by more than 30% over and above the UK benefits alone.[37] While the impact of other measures might vary, this suggests that the inclusion of this impact could have a significant impact on the estimation of benefits.

[37] Trans-boundary analysis was undertaken using the 100% precursor to secondary particle response function. If the 50% response function was used, then the increased economic benefits of Measure Q would be expected to be reduced.

119. Other areas of uncertainty that have been considered and would increase the benefits (but cannot be quantified with any certainty) include incorporating possible chronic morbidity effects, the inclusion of infant mortality, the inclusion of more minor effects in larger numbers of people (e.g. respiratory symptoms) and the inclusion of the effects of other pollutants such as nitrogen dioxide. All of these possible additional benefits are, however, considered to be small relative to the effect of particles on life expectancy.

120. Assuming the existence of an 'exposure window' for long term effects of particles (rather than exposure having an effect throughout life) could decrease the benefits substantially but there is insufficient evidence to judge the likelihood of this. Including the possible long term effect of ozone would also have the effect of decreasing the benefits estimates for many policies (as ozone concentrations are increased) but the evidence for a long term effect of ozone is weak compared with the evidence on particles. Considering hospital admissions as brought forward rather than additional would also decrease the benefits but only by a small amount.

5.4 Cost sensitivities

121. All the measures in the Air Quality Strategy have been analysed by undertaking a detailed cost benefit analysis for each measure.

122. Although the costs and benefits of the various policies have been analysed in detail, it is sometimes not possible to take into account all the impacts of a policy. The primary reason for this may be that it is not possible to assign a monetary estimate to the all the impacts of a policy, such as the loss in welfare to move into a smaller, more fuel efficient car as opposed to a less clean, larger family car.

123. Even in situations where all the categories of costs have been taken into account, there may be large uncertainties associated with these values forecasted into the future. It is essential to consider how future uncertainties as well as changes in key variables can affect the costs of the various measures and thus sensitivity analysis is fundamental to the process of assessing the choice between various options.

124. This section attempts to take into account the main, known uncertainties in the estimation of costs of each measure and through the use of sensitivity analysis predict the impact of any change in the costs on the decision making process. It should be noted, however, that our knowledge of cost uncertainties is in no way complete and therefore such sensitivity analysis is likely to capture only part of the overall uncertainties related to costs.

125. To undertake sensitivity analysis for the individual measures in the AQS it is necessary to be aware of the relevant uncertainties present in the analysis and whether those uncertainties have a positive or negative impact on costs. Table 5.11 presents a list of the uncertainties affecting the costs of each measure in the AQS and the perceived way in which these uncertainties are affecting the costs of the measures.

Table 5.11: Description of uncertainties of the costs of various additional measures in the Air Quality Strategy

<table>
<tr><th>Name of Measure</th><th>Description of Uncertainty</th><th>Impact of Uncertainty on Costs</th></tr>
<tr><td>Measure A: New Euro standard 5/6/V/VI – Low intensity</td><td rowspan="5">• Technology cost is the main component of the costs of these measures. Due to innovation the costs of Euro 5/6/V/VI technology may fall from what is currently estimated.
• Congestion benefits due to the impacts on fuel economies of vehicles by these technologies have not been incorporated in the cost estimates due to the lack of a quantification methodology.</td><td rowspan="5">• The costs are expected to be lower if these uncertainties are taken into account.
• The technology costs may be lower due innovation.
• The impacts on congestion are uncertain as petrol LDVs impacted by this measure have positive impacts on fuel economies which lead to higher. congestion costs and total costs, whilst the diesel vehicles impacted by this measure have fuel penalties and hence should lead to lower congestion costs.</td></tr>
<tr><td>Measure A2: Revised Euro standard 5/6/V/VI scenario</td></tr>
<tr><td>Measure B: New Euro standard 5/6/V/VI – High intensity</td></tr>
<tr><td>Measure C: Programme of incentives for early uptake of Euro 5/6/V/VI (low intensity)</td></tr>
<tr><td>Measure C2: Programme of incentives for early uptake of Euro 5/6/V/VI standards (revised scenario)</td></tr>
</table>

Name of Measure	Description of Uncertainty	Impact of Uncertainty on Costs
Measure D: Programme of incentives to phase out the most polluting vehicles (e.g. pre-Euro)	• **Safety:** There are likely to be significant safety benefits to the removal of older cars from the road. These have not been included due to lack of data. • **Welfare benefits:** There may be additional welfare benefits derived from changing an old car for a newer one. • **Administration costs:** Administration costs have not been estimated. • **Deadweight loss:** Deadweight losses from distortion of the decision to scrap the cars have not been estimated due to a lack of quantification methodology. • **Emissions from production and scrappage:** Emissions from production and scrappage are likely to be between 15-30% of total lifetime carbon emissions for the cars. Thus shortening the lifetime of cars may have a negative impact on average carbon emissions.[38]	• **Safety:** This impact is expected to reduce costs • **Welfare benefits:** Costs will be lower if this uncertainty is taken into account • **Administration:** Costs will be higher if administration costs can be taken into account • **Deadweight loss:** This will raise costs if taken into account • **Emissions from production and scrappage:** This is expected to have a negative impact on costs if taken into account • **Overall Impact of Uncertainties:** Unknown

[38] See Teufel et al (1996) and Elghali et al (2004).

Name of Measure	Description of Uncertainty	Impact of Uncertainty on Costs
Measure E: Updated programme of incentives to increase penetration of low emissions vehicles	• The **welfare costs** that the individuals may face when substituting to a LEV from a standard Euro 4 vehicle. • The **technology costs** for LEVs with the degree of specification are very difficult to estimate therefore the costs estimates are subject to a high degree of uncertainty.	• Accounting for welfare costs will lead to a rise in the cost estimates. • The uncertainties in the technology costs could be in either direction.
Measure F: Impact of national road pricing scheme on air quality	• There is major uncertainty about possible implementation options for this measure. The CBA assumes a national approach and mandatory use of on board units. There are of, course, alternative, more localised solutions which may imply different costs. • Uncertainty on the **technology costs** of the on-board units to be used for the scheme.	• The uncertainties in costs are substantial and could be in either direction.
Measure G: Extend London LEZ to Greater London and 7 largest urban areas	• There is some uncertainty regarding the enforcement method of this scheme. The set-up and the operational costs are dependent on the enforcement method chosen. The two enforcement methods are manual or automatic enforcement of the scheme. • There is some uncertainty regarding the response of the operators of non-compliant vehicles to this scheme.	• If automatic enforcement method is chosen, the set up costs are higher compared to the manual enforcement however the running costs are lower. • The costs of this scheme will depend on the ability to switch fleets around to move compliant vehicles onto London routes, and older vehicles outside London.

Name of Measure	Description of Uncertainty	Impact of Uncertainty on Costs
Measure H: Retrofit (Diesel Particulate Filters) DPFs on HDV and captive fleets (buses and coaches)	• Technology cost is the main component of the costs of this measure. Due to innovation the costs of Euro V/VI technology may fall from what is currently estimated. • Congestion benefits due to the negative impacts on fuel economies are no longer a main uncertainty to consider. This is because more recent information suggests that there will be impact on fuel economies from the retrofit of DPFs, as discussed in Chapter 3.	• The costs should be lower if this uncertainty is taken into account.
Measure I: Domestic combustion: switch from coal to natural gas or oil	• The additional infrastructure costs (such as new gas pipelines) of increasing the availability of natural gas and oil to those households currently using solid fuel boilers has not been included. • Potential increases in energy efficiency of the replacement boiler and differential fuel prices are expected to result in some net changes in fuel costs.	• Incorporating infrastructure costs would lead to an increase in costs of the measure. • Recent data on relative fuel costs indicate potential cost savings • Thus the overall effect on the costs of this measure is uncertain.
Measure J: Domestic combustion: Product standards for gas fired appliances which require tighter NO_X emission standards.	• A 20 year lifespan of existing 'high NO_X' boilers is assumed in the project specification. A shorter (15 year) lifespan may be more realistic. • Energy efficiency gains from this measure have not been quantified and therefore the costs are overestimated.	• The impact of a shorter lifespan would lead to an increase in costs. • Accounting for this uncertainty of energy efficiency impacts would lead to reductions in the costs.

Name of Measure	Description of Uncertainty	Impact of Uncertainty on Costs
Measure K: Large combustion plant measure	• A considerable uncertainty of the CAPEX of fitting such equipment particularly given the short timescale before 2010 that may exacerbate scarcity.	• The impact of higher CAPEX costs would lead to an increase in overall costs.
Measure L: Small combustion plant measure	• Uncertainty with regard to the likely choice and level of uptake of this measure. This has not been defined explicitly.	• The costs could be impacted either way.
Measure M: Reducing national VOC emissions by 10%	• The costs for PVR Stage II controls assume an economic lifetime of 15 years for the equipment (to be consistent with the methodology used to calculate the emission reductions). Shorter lifetimes have also been considered as sensitivity analysis below.	• The 15 year lifetime used in the costs results in lower total annualised costs, compared to using a shorter lifetime.
Measure N: Shipping measure through IMO	• The costs for this measure have been calculating assuming that the emission reductions are obtained using advanced IEM technology. An alternative technology (SCR technology) could have been used to achieve these emission reductions.	• This will have a positive impact on the costs of the measure.

5.4.1.1 Past evidence

126. Past evidence especially from the Evaluation of the Air Quality Strategy[39] has shown that the ex-post implementation costs of many policies have been less than the predicted (ex-ante) costs.

[39] 'An Evaluation of the Air Quality Strategy' Defra, (2005a).
Available at http://www.defra.gov.uk/environment/airquality/strategy/evaluation/report-index.htm

127. The study assessed the reasons for some of the differences between ex-ante and ex-post costs. It was concluded that there are sometimes errors from the baseline predictions. There are also often omissions of measures that allow cost-effective reductions (options other than end of pipe, consideration of technological innovation, etc.). The study stressed to have found no evidence of industry providing exaggerated cost estimates, but that the costs that were put forward by industry was usually based on pessimistic/'worst case' assumptions, or with a limited field of reference (i.e. without potential advances (learning), new measures, the fall of costs with large scale production, etc.). Moreover, in many cases the ex-ante costs are based on specific technical components, that in practice, the manufacturers did not need to fit to comply with new legislation.

128. The study arrived at the conclusion that 'legislation itself acts as a spur to research and innovation'.

129. The study presented a broad overview of the differences in the ex-ante and ex-post costs of the road transport and ESI measures and this is presented in Tables 5.12 and 5.13 below. From the tables we see that the differences in the ex-ante and ex-post cost of both road transport and ESI sectors are quite significant.

Table 5.12: Summary of ex-ante costs and ex-post costs in the road transport sector (1990 – 2001)

Policy	Ex-Ante Cost low to high	Ex-Post Cost low to high
Unleaded petrol	£2,590M	£1,036M (though probably lower)
Euro I petrol cars	£5,834M – £8,751M	£437M – £729M
Euro I diesel	£2,273M – £2,970M	Not known
1996 low sulphur	£561M	Not known
Euro II all vehicles	£3,197M – £6,189M	Not known
2000 fuel standards	£737M	£ 368 M
Euro III all vehicles	£648M – £739M	Not known
2005 fuel in 2000/1	£270M	£135M
Euro IV all vehicles	Not in evaluation period	Not yet available
All Policies	**£16,109M – £22,807M**	**Estimated £2,000M – £4,000M**

* Based on component costs only, it does not include development costs.

It must be stressed that the total of ex-post costs for the road transport sector are indicative only. A further detailed ex-post evaluation is needed to confirm this value.

Table 5.13: Summary of ex-ante costs and ex-post costs in for the electricity sector (1990 – 2001)

Policy	Ex-Ante Cost low to high	Ex-Post Cost low to high
UNECE		
1st Sulphur Protocol	£4,609M to £2,8905M	0 to £4,818M
2nd Sulphur Protocol	£800M	0 to 29M
Environment policy		
Reduction in Fuel Oil "S" content	£55M to £125M	Not known
IPC		
Low sulphur coal	£484M	0
FGD	£900M	£935M excluding operating costs)
Low NO_X burners	£180M	£83M
Particulate abatement	Not estimated	Not estimated
Renewables		
NFFO (all)	Not estimated	£600M to 1999 Assume ~£900M to 2001
All policies	**~ £6,000M to ~ £30,000M**	**~ £2,000M**
Note: Because policies have different implementation dates, the absolute costs and benefits appear very different for different policies in the evaluation period.		

130. Other studies also suggest significant differences in ex-ante and ex-post costs. A study on the regulation of industrial water pollution in the United States[40] found capital costs were, on average, overestimated by 72 per cent and operating and maintenance costs by 117 per cent. In addition, a report to the California Air Resources Board,[41] on the costs of adopting regulations to control greenhouse gas emissions from motor vehicles, found regulators overestimated costs by between 20 and 80 per cent.

131. This evidence is used to inform the sensitivity analysis performed on the measures in the Air Quality Strategy as outlined below.

40 Harrington, W. (2003) 'Regulating Industrial Water Pollution in the United States', Discussion Paper 03-03, Washington DC: Resources for the Future

41 Hwang and Doniger (2004) 'Comments on the Proposed Adoption of Regulations by the California Air Resources Board (CARB) to Control Greenhouse Gas Emissions from Motor Vehicles', Los Angeles: National Resources Defense Council,

5.4.1.2 Sensitivity analysis methodology

132. The HM Treasury Green Book[42] recommends using "switching values" to assess sensitivities of impacts. It states that "the calculation of switching values shows by how much a variable would have to fall (if it is a benefit) or rise (if it is a cost) to make it not worth undertaking an option".

133. The sensitivity methodology described in this section is loosely based on the above. The various schemes analysed in the Air Quality Strategy have a range of (annualised) NPVs, ranging from highly positive to highly negative. This method calculates the changes necessary in annualised cost estimates to "switch" the NPVs. For example, if the NPV of a scheme is negative, this method estimates the decrease in total annualised costs necessary to switch the NPV into positive territory and vice versa.

134. It is thus necessary to consider magnitudes of the changes in costs suggested by this methodology and make a value judgement based on the uncertainties described in Table 5.11 above and the past evidence outlined in section 5.4.1.1 above to assess whether these changes suggested by the sensitivity analysis are relevant for this particular scheme.

135. Tables 5.14 and 5.15 below shows the impact of this sensitivity analysis on the costs of the various measures in the transport sector and the industrial, domestic and shipping sectors respectively.

136. The tables show the percentage fall/rise in the costs required to effectively switch the NPV from the current level. The numbers in brackets imply negative percentages. The results in the table take either of the following explanations:

- If the costs of the measure is higher than the benefits, then the table shows the percentage fall in costs required to "switch" the NPV to zero. In this situation the percentages shown are negative implying a fall in costs required. Thus effectively, the costs need to change by more than – x% for the NPV to be positive.
- Similarly, if the benefits of the measure are higher than the costs, then the table shows the percentage rise in costs required to "switch" the NPV to zero. In this situation the percentages shown are positive implying a rise in costs required. Thus effectively, the costs need to change by more than + x% for the NPV to be negative.

137. Ranges with the NPVs account for the effect of the lags, wherein the lower end represents the 40 year lag time and the upper end of the range assumes a zero lag time between changes in PM concentration and chronic health impacts.

138. The results of sensitivity analysis below are then compared with the uncertainties presented in Table 5.11 above and conclusions drawn.

[42] See http://greenbook.treasury.gov.uk/chapter05.htm#introduction

Table 5.14: Sensitivity analysis of additional transport measures

List of Measures	Annual PV of total Costs (£ million)	% costs have to fall/rise for NPV to be equal to zero
Measure A: Euro Standard 5/V (Low Scenario)	382 – 389	21% – 210%
Measure A2: Revised Euro Standard 5/V	788 – 793	(33%) – 68%
Measure B: Euro Standard 5/V (High Scenario)	983 – 1,003	(42%) – 49%
Measure C: Incentivising early uptake of Euro 5/6/V/VI	409 – 417	35% – 232%
Measure C2: Incentivising revised early uptake of Euro 5/6/V/VI	816 – 823	(30%) – 73%
Measure D1: Programme of incentives to phase out most polluting vehicles	5	(80%) – (60%)
Measure D2: Programme of incentives to phase out most polluting vehicles	112	(87%) – (83%)
Measure E: Programme of incentives to increase penetration of LEVs into the UK Fleet	61	103% – 184%
Measure F: Impact of road user charging schemes on air quality	N/A	N/A
Measure G1: LEZ implemented in London (first phase)	18 – 45	(73%) – (6%)
Measure G2: LEZ implemented in London (Phase 2)	33 – 88	(76%) – (6%)
Measure G3: LEZ implemented in 7 largest urban areas outside London	19	(73%) – (63%)
Measure H1: Retrofit DPFs on HDV, captive fleet buses and coaches (65%)	68	(49%) – (25%)
Measure H2: Retrofit DPFs on HDV, captive fleet buses and coaches (20%)	14	(28%) – 0%
Measure H3: Retrofit DPFs on HDV, captive fleet buses and coaches (35%)	25	(28%) – 5%

5.4.1.3 General conclusions regarding the sensitivity analysis for road transport measures

139. From the table above we can make the following conclusions regarding each measure:

- Measure D has a high level of uncertainty associated with the costs outlined in Table 5.11 above. The sensitivities presented above show that the costs have to fall between 60 – 87% for the measure to show positive net benefits. Although a number of uncertainties regarding the costs have been described, the overall impact if these uncertainties are taken into account on costs is unknown. Therefore it is difficult to assess whether such a reduction in costs might be achievable.
- Due to the high air quality and carbon benefits of Measure E, the benefits are much higher than the costs. However there are some uncertainties which may affect the costs as shown in Table 5.11. These are analysed in more detail in section 5.4.1.5 below.
- The sensitivity analysis shown in Table 5.14 above for Measure H shows that the reductions in costs needed to achieve a positive NPV for the 6% hazard rate scenario are broadly similar to the differences between the ex-ante and ex-post costs presented for the transport measures (see Table 5.12).

Table 5.15: Sensitivity analysis of additional industrial, domestic, shipping and combined measures

List of Measures	Annual PV of total Costs (£ million)	% costs have to fall/ rise for NPV to be equal to zero
Measure I: Domestic Combustion 100% switch from coal to Natural Gas – UK wide	43	(53%) – (35%)
Measure J: Domestic Combustion – Product Standards – UK wide	196	(96%) – (76%)
Measure K1: SCR on Coal fired power stations in 2010 instead of 2016 – short term measure	118 – 206	(52%) – (28%)
Measure K2: SCR on Gas fired power stations, I & S and Refineries in 2010 – long term measure	273	(85%) – (51%)
Measure L: Small Combustion plants – Combined costs for SO_2 and NO_X reductions	9	200% – 633%
Measure M: Reducing national VOC emissions by 10%	249	(100%)
Measure N: Shipping measure	1	24,500% – 57,600%
Measure O: Combined measure C + E	470 – 478	39% – 208%
Measure P: Combined measure C + L	418 – 426	38% – 229%
Measure Q: Combined measure C + E + L	479 – 487	42% – 220%
Measure R: Combined measure C2 + E + N	878 – 885	4% – 138%

5.4.1.4 General conclusions regarding the sensitivity analysis for industrial, domestic, shipping and combined measures

140. From the table above we can make the following conclusions regarding each measure:

- One of the uncertainties noted for Measure I has been the exclusion of the additional infrastructure costs, and if this is taken into account costs of the measure would rise rather than fall. However the impact of energy efficiency on the costs of the measure would lead to a fall in the costs. It needs to be ascertained which impact is stronger. The fall in annualised costs required for the NPV to "switch" from negative to positive ranges between 35 – 53%. It is not clear if the overall impact of the uncertainties is enough to result in this "switch".

- Similar to Measure I, the uncertainties notes for Measure J can affect the costs both positively and negatively and therefore it is not possible to determine whether the overall effect of the uncertainties would lead to a fall in costs which this measures requires to have a positive NPV.
- The only uncertainty noted for Measure L is the likely choice and level of uptake of this measure. The rise in costs required for the NPV to be negative is quite large and there are no uncertainties noted for this within the current analysis which could affect the costs in this manner. However it must be noted that further analysis may lead to revisions in this estimate.
- The only uncertainties noted for Measure M in Table 5.11 relates to the lifetime of this technology with shorter lifetimes considered as a sensitivity. The table above shows that the costs have to fall by a substantial amount to achieve a positive net benefit for this measure. Although the efficiency gains for this measure could result in a fall in the costs of this measure, a separate sensitivity analysis has been conducted in section 5.4.1.5 below which considers the impacts of this measure when the operating lifetimes of the PVRII technology is altered. PVRII technology is one of the technologies considered in this measure which helps achieve the emission reductions.
- Sensitivity analysis of Measure N is presented in section 5.4.1.5 below. This measure has high annualised benefits compared to the costs. Therefore according to the sensitivity analysis presented in Table 5.15 above the costs have to rise by significant amounts (57,600% for the low end estimate) for this measure to have any changes in the direction of its NPV.
- For the combined measures, the costs are assumed to be additive and therefore any uncertainties identified for the relevant individual measures will be cumulative.

5.4.1.5 Further sensitivity analysis of specific measures

141. Further to the generalised sensitivity analysis described above, specific sensitivity analysis needs to be conducted for some measures which have a higher degree of uncertainty in specific elements of the estimates and for which alternative assumptions can be applied, enabling quantification.

142. Four of the measures outlined above have been considered here for an even more detailed sensitivity analysis. These measures are outlined below.

Measure E – Updated programme of incentives to increase penetration of low emissions vehicles

143. As explained in Table 5.11 above, the costs of this measure have some degree of uncertainty. For the current analysis of this measure (presented in Chapter 3, section 3.2.5) the costs have been estimated based on the difference between vehicles meeting the LEV emissions specified in the measure and 'equivalent' cars that have higher emissions i.e. cars of a similar size, and with similar engine sizes.

144. The incremental resource costs of an LEV from a standard Euro IV compliant vehicle includes the difference in the retail prices of the vehicles as well as a welfare cost component. It is assumed that most individuals prefer the standard Euro IV vehicles

and incur large welfare costs when they shift to the smaller LEVs. This welfare cost is incorporated into the incremental resource cost of the LEV compared to the standard Euro IV.

145. The welfare costs portion of the incremental costs of an LEV over a standard Euro IV can be divided into two parts:

- As the LEV represents a reduction/increase in utility/quality compared with that offered by the comparator vehicle, (e.g. smaller, poorer performance, etc.) the quantified loss of utility is added to the purchase price of the LEV. This utility/quality cost is calculated using a hedonic price model.
- Resistance to change of switching to new technologies. Market research studies[43] have surveyed motorists to estimate the additional annual running costs that they would endure before they switched to (1) a vehicle with a different fuel system/ technology; (2) a vehicle with a smaller engine; and (3) a physically smaller car.

146. However there is a large degree of uncertainty regarding whether the welfare costs should only comprise the utility quality cost or both costs presented above. It was considered that using both the costs noted above to estimate welfare costs of an LEV would lead to some double counting of costs of this measure. As a result, Chapter 3 presents the analysis of this measure incorporating only quality costs. This section presents the impacts on the costs of the measure and hence the NPV when the welfare cost incorporates both the components described above.

147. Further sensitivity analyses of the incremental costs of the LEV are presented in Table 5.16 below.

Table 5.16: Sensitivity analysis of technology costs of LEVs

	Current estimated technology costs for petrol LEVs	Technology Costs for petrol LEVs (Sensitivity Analysis)	Current estimated technology costs for diesel LEVs	Technology Costs for diesel LEVs (Sensitivity Analysis)
Extra cost of LEV over comparable Euro 4 vehicles	£600	£1,919	£1,200	£2,532

148. The revised cost benefit assessment of Measure E due to the revised technology estimates is presented in Table 5.17 below.

[43] RAC (2004) 'Counting the Cost, Cutting Congestion'. Research by Morpace International on behalf of RAC.

Table 5.17: Sensitivity analysis using revised technology costs of LEVs

	Annual PV of total Costs (£ million)	Annual NPV (£ million)
Measure E: Original technology costs	61	63 – 112
Measure E: Revised technology costs	563	(439) – (390)

149. Thus using the revised technology costs of Measure E, the cost benefit assessment shows that this measure looks substantially worse than the original analysis.

Measure H – Retrofit Diesel Particulate Filters on HDV and captive fleets (buses and coaches).

150. The majority of the costs of these measures are determined by the capital and operating costs associated with Diesel Particulate Filters (DPFs). These costs have changed substantially owing to new information received during the consultation period.

151. The key driver of these revisions is a substantial reduction in the resource cost of this technology, where unit costs have been reduced by up to 55%. While these changes are presented in the central analysis as the best available estimates some uncertainty remains on the magnitude of this change. Therefore a sensitivity analysis has been undertaken using an alternative estimate of resource costs based on market data from comparable industries.

152. The sensitivity assumptions of technology costs of the DPFs are presented in Table 5.18 below.

Table 5.18: Sensitivity analysis of technology costs of DPFs

	Current estimated technology costs DPFs	Technology Costs for DPFs (Sensitivity Analysis)
Extra cost of DPFs for Articulated HGVs	£1,750	£3,050
Extra cost of DPFs for Rigid HGVs	£1,350	£2,300
Extra cost of DPFs for Captive Fleet	£1,350	£2,300

153. The revised cost benefit assessment of Measure H due to the sensitivity technology estimates is presented in Table 5.19 below.

Table 5.19: Sensitivity analysis using sensitivity technology costs of DPFs

	Annual PV of total Costs (£ million)	Annual NPV (£ million)
Measure H1: sensitivity technology costs	77	(42) – (26)
Measure H2: sensitivity technology costs	22	(12) – (8)
Measure H3: sensitivity technology costs	38	(20) – (12)

154. Using the alternative technology costs the cost benefit assessment shows that the present value of costs exceeding benefits for all these measures.

Measure M: Reducing national VOC emissions by 10%

155. The capital and operating costs of this measure depend on the VOC reduction technologies considered. The different technologies considered and the sources of costs for each of these technologies can be obtained in Chapter 3 (section 3.3.5).

156. One of the technologies considered for this measure, the PVR Stage II technology, assumes an economic lifetime of 15 years for the equipment. The 15 year lifetime used in the above costs results in lower total annualised costs, compared to using a shorter lifetime. However, 15 years was considered as the central analysis to be consistent with the methodology used to calculate the emission reductions.

157. This section presents the impacts of the costs of the measure by considering shorter lifetimes of the technology. As the measure is a long term measure, considering a technology with a shorter lifetime implies that the equipment will have to be replaced more often during the life of the measure and as a result, incurring higher capital costs over time.

158. The analysis presents the impact on the costs and subsequently the annualised NPV of the measure when the operating lifetime of the PVRII technology is reduced from 15 years to 10 years and 5 years respectively.

Table 5.20: Sensitivity analysis of PVRII costs for Measure M

Operating Life of PVR Stage II technology	Total Annualised technology cost of PVR Stage II equipment over the lifetime of the measure (including capital and operating costs) – £million	Total Annualised Cost of the Measure (£million)
15	13.2	249
10	17.7	254
5	31.6	268

159. The three estimates annualised cost of the measure are now subtracted from the benefits of this measure for the different hazard rates considered. The impact on the NPV of this measure by altering the lifetimes of the technology is presented in Table 5.21 below.

Table 5.21: Sensitivity analysis using revised PVRII costs

	Annual PV of total Costs (£ million)	Annual NPV (£ million)
Current Version of Measure M: Assuming a 15 year lifetime of PVR Stage II technology	249	(249)
Sensitivity Analysis of Measure M: Assuming a 10 year lifetime of PVR Stage II technology)	254	(254)
Sensitivity analysis of Measure M: Assuming a 5 year lifetime of PVR Stage II technology	268	(268)

160. It can be noted from Table 5.21 above that the overall result of the analysis does not change a great deal from this sensitivity analysis: the measure still shows a consistently negative NPV across the different sensitivities. The sensitivity analysis only strengthens this message.

Measure N – Shipping: the global shipping fleet is required to use 1% sulphur fuel and reduce NO_X emissions by 25%

161. Sensitivity analysis has been undertaken on this measure in relation to two key factors: firstly the duration of changes in concentrations; and the technology employed to achieve the reductions. This section considers each of these areas in turn.

162. The first sensitivity relates to the relevant duration of any changes in concentrations arising from this measure. As a result of uncertainties in the future development of shipping industry it was suggested that a relevant alternative duration for the consideration of this measure would be 20 years. Such a change in duration clearly has implications both for the costs and benefits of this measure.

163. This analysis has been undertaken on a consistent basis with the assessment set out in section 3.3. The results of this analysis are presented in Table 5.22.

Table 5.22: Annual costs and benefits of implementing Measure N in the UK (£millions)[a]

Annual PV of Costs	Annual PV of Benefits	Annual NPV
1	317 – 500	316 – 499

[a] Numbers in brackets represent negative values.

164. The table above shows that the benefits outweigh the costs of measure N for both the lag and no-lag scenarios assuming that the change would only last 20 years.

165. In relation to the applied technology two solutions were considered to achieve the reductions in NO_X emissions:

- Advanced internal engine modifications (IEM) technology. This solution was considered to be consistent with the definition of Measure N since it is estimated to achieve around a 30% improvement in NO_X emissions
- Selective catalytic reduction technology (SCR). The SCR solution would achieve emissions reductions well in excess of those defined in the measure (up to 90%).

166. This section presents a sensitivity analysis of the costs of this measure considering the alternative technology of SCR.

167. As this is a long term measure, the costs and benefits of Measure N have been estimated to 2109. The assumed lifetime of the SCR technology is 15 years; the capital costs have therefore been replicated every 15 years over the period 2010 to 2109.

168. Table 5.23 below presents the annualised costs for both the current analysis as well as for the sensitivity analysis using the SCR technology. The resulting NPVs of the measure for the different hazard rates considered are also presented in Table 5.18 below.

Table 5.23: Sensitivity analysis using differing technologies for Measure N

	Annual PV of total Costs (£ million)	Annual NPV (£ million)
Current Version of Measure N: Using the Advanced IEM technology	1.07	242 - 573
Sensitivity analysis of Measure: Using the SCR technology	1.6	241 - 572

169. From the table above it can be noted that the sensitivity analysis of the measure has not altered the results of the measure. This measure still provides high positive net benefits even using the more expensive SCR technology.

5.5 Uncertainties in ecosystem assessments

170. There are two main areas of uncertainty in relation to the ecosystem assessment:

- definition and projection of the baseline and measures; and
- definition and application of critical loads.

171. The first area is essentially the same as for the other assessments (cost and benefit, exceedence and qualitative), albeit with an additional modelling phase using the FRAME and CBED models. These uncertainties are discussed in section 5.2 above.

172. There are a number of areas on uncertainty relating to the definition and application of critical loads. Despite its usefulness, the concept is still a relatively new approach in environmental science and therefore contains assumptions, parameters and data which need wider testing to validate the methods of assessment. It is important to understand that different sources of information are used to set different critical load or critical level values. For SO_2, the values are primarily derived from field observations, while for O_3, the primary source is exposure response studies in field chambers, and for NO_X and NH_3 the primary source is experimental studies. The empirical critical loads of total nitrogen deposition for vegetation were derived primarily from field experiments and observations. It is important to note that there is uncertainty attached to all these values, which has implications for interpretation of data showing areas where they are exceeded.

173. In addition to noting the limitations to the methods of calculating critical loads it is important to flag some of the assumptions made in mapping critical loads for both freshwater and terrestrial ecosystems. For example, in the soils work no account is taken of the soil variability within each 1km square, as the classes were assigned for the dominant soil type present. For freshwaters each 10x10 km grid square is represented by a single spot sample from one water body within the square. While a screening procedure to identify the most sensitive water body in the square was used it is highly unlikely that the results of a single sample represent the spatial and temporal variation in water chemistry (and hence critical load) within the square. Similarly in calculating exceedence spatial (and temporal) variation in deposition inputs can considerably change the estimates of ecosystems potentially at risk of damage. Currently deposition is calculated on a 5x5 km grid and a mean value for the square is given. In reality the most sensitive ecosystems are in upland areas where altitude will vary considerably leading to significant changes in pollutant deposition across these grid squares. These gradients in deposition are currently masked and not accounted for in exceedence maps. All of these simplifying procedures have direct implications on the use and interpretation of the maps particular at small scales which are often the focus of concern for nature conservation.

174. To improve the utility of critical loads and their exceedence there is a growing need to build on our knowledge of the dose-response relationships for different species. Secondly there is a need to consider the growing role of nitrogen as sulphur emissions decline. Currently the co-effects of nitrogen deposition with sulphur and the moderating effects of base cation deposition are not taken into account. In dealing with nitrogen

alone there are several important gaps in our knowledge, the most important of which suggested by Bobbink and Roelofs (1995) are the effects of enhanced nitrogen deposition on soil fauna; effects on forest floor vegetation; and insufficient knowledge of the different effects of NO_X and NH_3 to produce separate critical loads.

175. Full details on modelling and mapping critical load (and levels) can be found by visiting the UK National Focal Centre: www.critloads.ceh.ac.uk

5.6 Monte Carlo analysis

176. To investigate the combined effects of the uncertainties set out in this chapter a Monte Carlo analysis has been undertaken on the main uncertainties for two of the measures considered for the Air Quality Strategy. This analysis has been undertaken both to test out this methodology for wider application and to consider the particular measures evaluated both of whose results show substantial variation.

177. Monte Carlo analysis is a risk modelling technique that uses estimated distributions of key parameters of the modelling to present ranges of possible outcomes, the probabilised distribution of values within that range and the expected value.

178. The two where this analysis have been applied are:

- Measure R – the combined measure of incentives for the early uptake of revised Euro standards (measure C2) and low emission vehicles (measure E) with work towards reducing the emissions from shipping (measure N); and
- Measure B – Euro standards 5/6/VI high reductions scenario

179. In modelling these measures the analysis has focussed on the key parameters that affect the monetary cost benefit analysis. The main considerations being the relative risk coefficient for chronic mortality (life years saved) from PM pollution,[44] the lag phase involved, and the valuation of a life year lost. The analysis also presents a scenario that includes an uncertainty on the costs of the measures based on the literature on ex ante and ex post costs.

180. Table 5.24 below provides the key results of this analysis providing the benefit and net benefit estimates from both Chapter 3 of this report and from the Monte Carlo analysis alongside the probability of a net benefit.

[44] Linear scaling was used. Future work may incorporate non-linear scaling.

Table 5.24: Monte Carlo analysis for measures R and B.

Measure		IGCB analysis[a]		Monte Carlo Analysis[b]		Probability of net benefit (single point costs)
		Annual benefit (£ billion)	Annual NPV (£ billion)	Annual benefit (£ billion)	Annual NPV (£ billion)	
R	Lowest	0.92	0.03	0.95	0.17	54%
	Highest	2.1	1.2	3.2	2.5	93%
	Best	n/a	n/a	2.0	1.2	75%
B	Lowest	0.57	(0.43)	0.71	(0.29)	26%
	Highest	1.5	0.51	2.0	1.0	70%
	Best	n/a	n/a	1.3	0.3	55%

[a] Highest and lowest values differ according to assumed lag of between 0 and 40 years

[b] Highest and lowest scenarios relate to different scenarios modelled in the MCA.

181. These result show that for both these measures the best estimate indicates a positive annual net present value for measures R and B, of £1.2bn and £0.3bn respectively.

182. It also estimates a 75% probability that the benefits of measure R would outweigh the costs and similarly a 55% chance for measure B. However, at present there is no generally accepted position on the necessary probability of gaining a net benefit to justify taking action. It has not therefore been possible on this occasion to apply these results directly in deciding which measures to take forward.

KEY UPDATES TO THE CHAPTER

This chapter has been updated to reflect changes to the measures assessed in this report and the revised results of the assessments presented in Chapters 3-5. A full description of the new measures considered, and the updates made to existing measures, can be found at the start of Chapter 3.

Further consideration has also been given to areas recommended for further research. This section has been updated to reflect recent additional areas work and methodological development carried out since the Third report and also takes the opportunity to set out additional areas for further work highlighted as part of the AQS consultation. This is discussed in more detail in section 6.3 of this chapter.

6.1 Introduction

1. This chapter presents the combined assessment using both monetary analysis and non-monetary (i.e. exceedences, ecosystems and other qualitative) assessments.

6.2 Combined assessments of all the measures in the AQS review

2. The options considered have been assessed using a common assessment framework, in order that they can be more easily compared, and assessed against the baseline.

3. Each option has been assessed against the following criteria:

- Monetary cost benefit analysis; and
- Impact on exceedences, ecosystems and qualitatively described effects such as distribution, noise and competitiveness.

4. Each of the assessments undertaken has uncertainties associated with it which should be borne in mind. It is also important that the results from each assessment are considered as a whole. Chapters 3 and 4 discuss each assessment in more detail and Chapter 5 discusses the uncertainties associated with the analysis.

5. This section presents the combined assessment of all the measures considered in this report, as part of the AQS review process, and is divided into the following subsections:

- **Section 6.2.1** deals with the monetary assessment of the measures and also presents the key messages from the cost-benefit sensitivity analysis and the new Monte Carlo analysis.
- **Section 6.2.2** presents a short summary of the exceedence, ecosystems and other non-monetary assessments of measures.
- **Section 6.2.3** combines the above and presents a full assessment of all the measures.

6. It must be noted that this chapter does not provide any details on the methodology used for the assessment of the measures or a detailed measure by measure discussion of the results. Instead the focus is on presenting a broad analysis of the results and presenting some overall conclusions.

6.2.1 Combined monetary assessment of measures

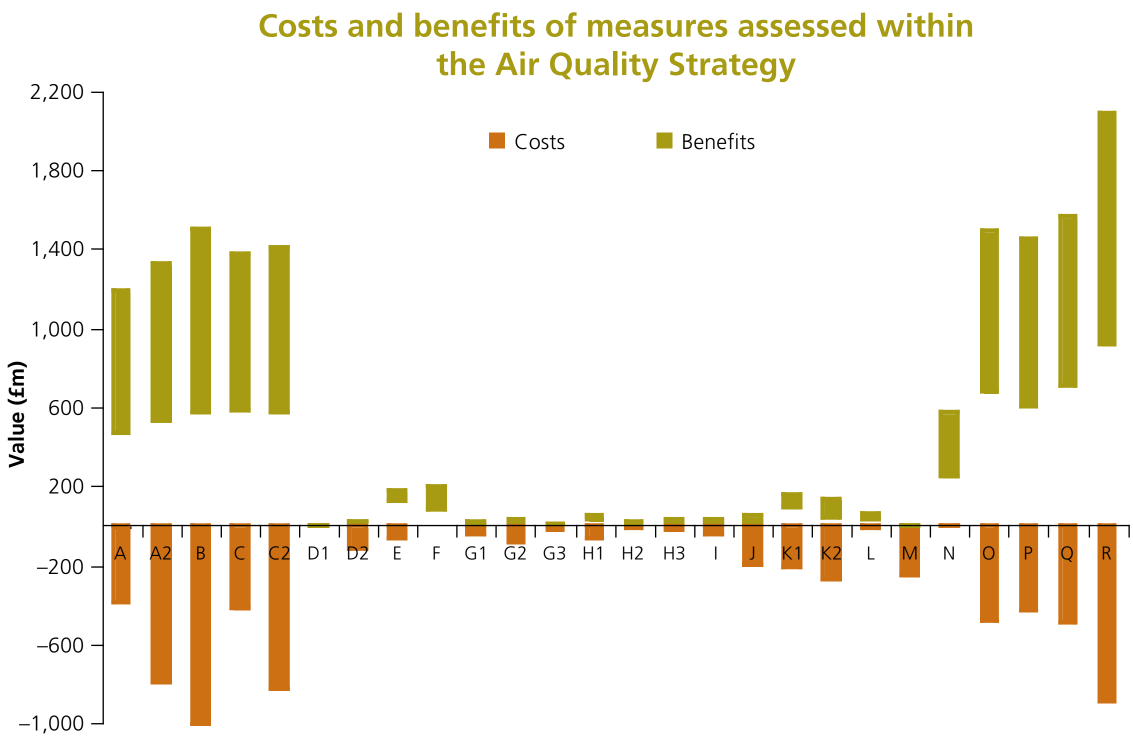
7. As described in Chapters 2 and 3, the benefits of all the additional measures are driven primarily by the health benefits accruing from the improvement of air quality compared to the baseline. The methodology for estimating the health benefits and the baseline is explained in Chapter 2 of this document. The costs of each measure depend on the resource costs of technologies used, operational costs, welfare costs, and the resource costs of fuel. The costs and benefits have been discounted using the standard Green Book discount rate and annualised to present the equivalent annual estimates.

8. The assessment methodology used to present the monetary assessment of the additional measures considers the difference between the annualised present value of benefits and the annualised present value of costs to estimate the net present value for each measure. The benefits of each measure are presented based on a 6% per 10μg.m^{-3} $PM_{2.5}$ hazard rate reduction as recommended by COMEAP in their 2006 interim statement.[1] This is discussed further in section 2.5.3 of Chapter 2.

9. Figure 6.1 below presents the costs and range of benefits of the additional policy measures. The lower bound of the ranges in the graph below represents the PV of benefits with the 40 year lag and the upper bound represents the PV of benefits with no lag. It should also be noted that the costs are presented as bars between the cost estimate, which are generally point estimates, and a value of zero. Costs are presented in this way to ensure visibility as point estimates or limited ranges are not clear on the diagrams scale. Therefore it should not be read that all costs have at the bottom of their range a zero cost.

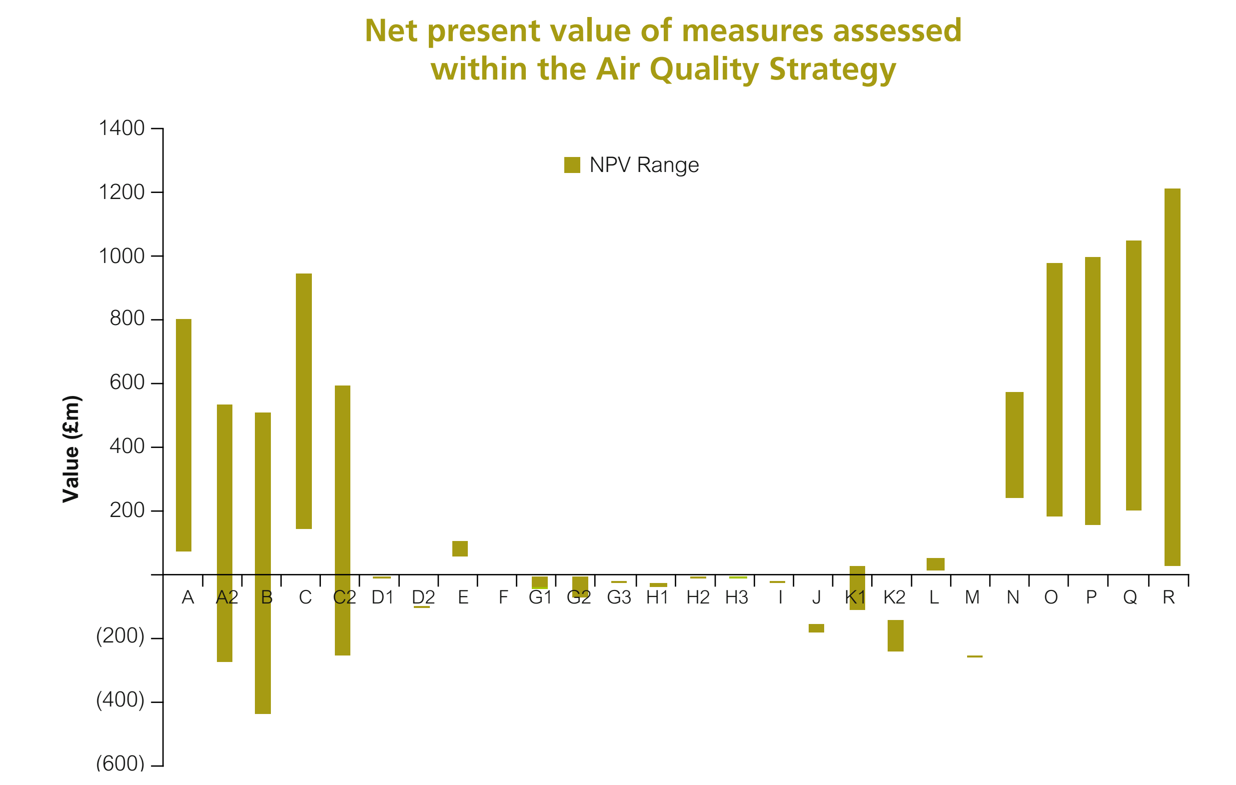
1 'Interim Statement on the Quantification of the Effects of Air Pollutants on Health in the UK', Committee on the Medical Effects of Air Pollutants, Department of Health (2006b).
Available at www.advisorybodies.doh.gov.uk/comeap/pdfs/interimlongtermeffects2006.pdf

Figure 6.1



10. Figure 6.2 below presents the range of the NPVs for the additional measures. As with Figure 6.1 above, the lower bound of the ranges in the graph below represents the NPV with the 40 year lag and the upper bound represents the NPV at the with no lag. Therefore there is a possibility for some measures that the NPV assessment could be partially negative and partially positive.

Figure 6.2



11. The following conclusions can be drawn from considering the graphical analysis of the NPVs of the additional measures. It must be noted that the conclusions presented below are only based on monetary cost benefits analysis, and do not consider the uncertainties affecting the monetary cost benefit analysis, or any non-monetary assessments. Full NPV results can be found in Table 6.3 later in the chapter.

- Measures A (Euro low), C (Early Euro low), E (LEV), L (SCP), N (Shipping), O, P, Q and R (combined measures) show positive NPVs, implying that the benefits of these measures are greater than the costs. However, comparing within these measures, Measures E and L have lower net present values relative to the remaining measures.
- Measures A2 (Euro revised), B (Euro high), C2 (Early Euro revised), H2 and H3 (Retrofit), K1 (LCP short term) present the possibility of having both a positive and negative NPV. This is primarily due to the lag times associated with PM_{10} health impacts, with a positive NPV likely when no lag is considered, and a negative NPV likely when the 40 year lag is taken into account. In its 2006 interim statement, COMEAP stated that its judgement tended towards a greater proportion of the effect occurring in the years soon after pollution reduction rather than later and this should be borne in mind when interpreting these results. Comparing within these measures, Measures A2, B and C2 have a higher NPV relative to Measure H.

- Measures D1, D2 (Phase out), G1, G2, G3 (LEZ), H1, (Retrofit), I (Domcom coal), J (Domcom NO_X), K2 (LCP long term) and M (VOC) show negative net present values implying that the costs of these measures outweigh the benefits.

12. It is necessary to take into account the key conclusions from the sensitivity analysis which may alter the results of the monetary assessment discussed above.

13. The uncertainties considered in Chapter 5 deal with both individual measure specific uncertainties (such as the impact on technological advances on specific technologies used in the measures) as well as general uncertainties (such as using alternative assumptions on the estimation of benefits of measures).

14. This section only considers the uncertainties which have a potential to alter the results of the monetary assessment and for which results have been estimated for each individual measure; it does not present the detailed list of uncertainties which is considered in Chapter 5 of this report. Note that these uncertainties do not necessarily have a high probability of applying.

15. Table 6.1 below discusses these measures and considers the effects these uncertainties will have on the NPV of these measures.

Table 6.1: Measures with significant uncertainties which impact costs and benefits

Measure	Benefit Uncertainty	Cost Uncertainty
Measure A (Euro low) **Measure C (Early Euro low)**	**No chronic mortality effects of particles:** The carbon and ozone disbenefits outweigh the other health benefits, including the acute mortality effects from reductions in particles and the measures have negative overall benefits. **Assuming 0.1% reduction in hazard rate per $\mu g.m^{-3}$ $PM_{2.5}$ (1% per 10$\mu g.m^{-3}$):** The NPV using the 6% hazard rate is positive but switches to negative using the 1% hazard rate.	**Technology costs fall due to innovation:** The impact of innovation on technology reduces the costs associated with these measures but this is not valued.

Measure	Benefit Uncertainty	Cost Uncertainty
Measure A2 (Euro revised) Measure B (Euro high) Measure C2 (Early Euro revised)	**No chronic mortality effects of particles:** The carbon and ozone disbenefits outweigh the other health benefits, including the acute mortality effects from reductions in particles and the measures have negative overall benefits. **Assuming 0.1% or 1.2% reduction in hazard rate per $\mu g.m^{-3}$ $PM_{2.5}$ (1 or 12% per 10$\mu g.m^{-3}$):** The lower bound of the NPV using the 6% hazard rate is negative but switches to positive using the 12% hazard rate. The upper bound of the NPV using the 6% hazard rate is positive but switches to negative using the 1% hazard rate. **Assuming different lagtime for long term effects of PM:** using a 6% hazard rate, this measure has a positive net present value assuming a zero lag effect (compared with a small negative net present value with a 40 year lag effect).	**Technology costs fall due to innovation:** The impact of innovation on technology reduces the costs associated with these measures but this is not valued.
Measure E (LEV)	**No chronic mortality effects of particles:** The benefits fall but are not negative. **Uncertainty regarding the social cost of carbon (SCC)[2]:** As this measure also reduces carbon emissions, using a higher value for SCC increases the benefits and using the lower bound of the SCC reduces the benefits. However using the lower value for SCC does not impact on the overall cost benefit conclusion for this measure.	Using different assumptions for valuing welfare costs arising from this measure. If more stringent assumptions are used for valuing welfare costs, the total costs of the measure would rise significantly.

[2] It is worth noting that the Stern review suggested that the cost of carbon used in government evaluations was significantly undervalued. The report suggested increasing the value to \$85 per tonne of CO_2 (approx £160 per tonne of carbon). However as this figure has not been agreed across government the existing agreed value has been used.

Measure	Benefit Uncertainty	Cost Uncertainty
Measure K (LCP)	**No chronic mortality effects of particles:** The net benefits of the measure (K1 short term and K2 long term) are negative as the carbon and ozone disbenefits outweigh the other health benefits, including the acute mortality effects from reductions in particles. **Assuming 0.1% or 1.2% reduction in hazard rate per $\mu g.m^{-3}$ $PM_{2.5}$ (1 or 12% per 10$\mu g.m^{-3}$):** The upper bound of the NPV for K1 is positive but switches to negative using the 1% hazard rate. **Assuming different lagtime for long term effects of PM:** using a 6% hazard rate, this measure (K1 short term) has a positive net present value assuming a zero lag effect (compared with a negative net present value with a 40 year lag effect)	Uncertainty associated with which coal power stations will opt for the limited life derogation under the LCPD and what baseline NO_X abatement measures will be adopted by opted in plants
Measure L (SCP)	**No chronic mortality effects of particles:** The net benefits of the long term measure (Measure L) are negative as the carbon and ozone disbenefits outweigh the other health benefits, included the acute mortality effects from reductions in particles. **Uncertainty regarding the social cost of carbon (SCC)[3]:** As this measure also reduces carbon emissions, using a higher value for SCC increases the benefits and using the lower bound of the SCC reduces the benefits. Using the lower value does not impact on the overall cost benefit conclusion for this measure.	This measure has been defined at a very high level. There is uncertainty as to the implementation route and take-up rate which could impact costs.

16. Monte Carlo analysis has also been carried out to assess the effect of key uncertainties on the results of the monetary assessment. The results of this analysis is presented in section 5.6 of Chapter 5 with the full analysis available in Annex 7.

[3] op cite 2

6.2.2 Combined non-monetary assessment of measures

17. This section presents a combined analysis of all the non-monetary assessments of the measures in the Air Quality Strategy review. A detailed discussion of the assessments of each measure and the methodology used to derive them is presented in Chapter 4. This section attempts to draw out the major messages from Chapter 4 and provides a summary of the non-monetary assessments undertaken.

6.2.2.1 Exceedences

18. The impact of the measures on exceedences was discussed in detail in section 4.2 of Chapter 4 of this report. Figures 6.3 and 6.4 below summarise the impact of the measures on the extent of exceedences of objectives. They show the reduction in extent of exceedence of objectives at background or at urban roadside in 2020. The higher the bar, the more effective the measure is likely to be for reducing exceedences.

Figure 6.3

Reduction in exceedences at urban roadside, in comparison to the baseline in 2020

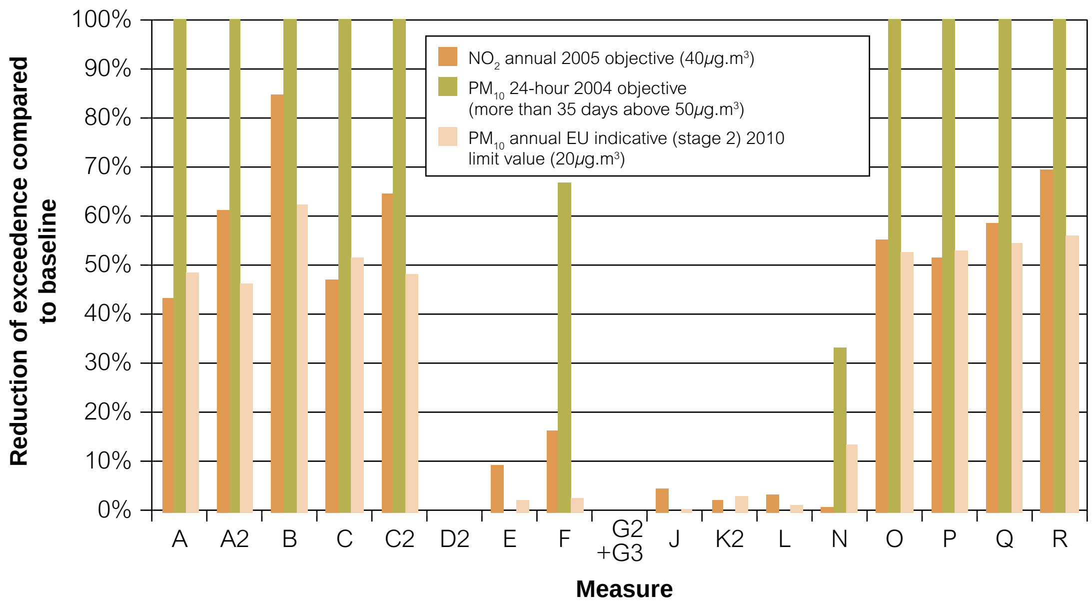
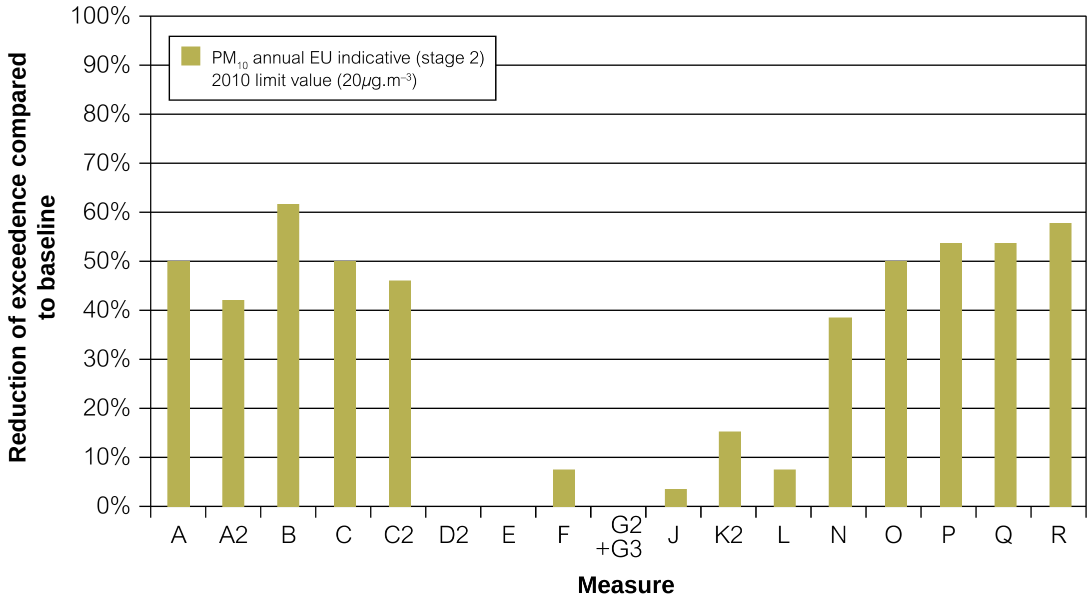


Figure 6.4

Reduction in exceedences at background area, compared to the baseline in 2020



19. The figures above show that Measures A (Euro low), A2 (Euro revised), B (Euro high), C (Early Euro low), C2 (Early Euro revised), F (Road pricing), N (Shipping) and the combined Measures (O, P, Q and R) are expected to have significant impact on exceedences overall (incorporating both roadside and background exceedences).

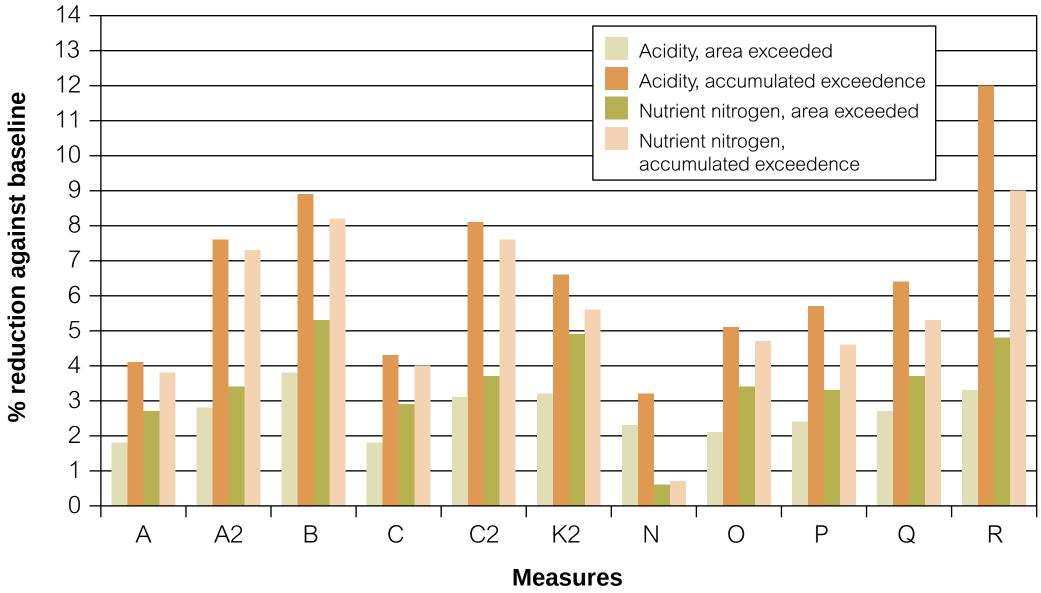
6.2.2.2 Ecosystems

20. For the ecosystem assessment, the measures which were anticipated to have the most significant impact on critical loads (i.e. those measures that would affect SO_2, NO_X or NH_X emissions) were quantified.

21. Figure 6.5 below shows the quantified impacts on ecosystems of those measures expected to generate a significant impact on critical loads.

Figure 6.5

Reduction in areas exceeded and accumulated exceedence against baseline, for acidity and nutrient nitrogen critical load exceedence



22. The chart shows that Measures B (Euro high) C2 (Early Euro revised), A2 (Euro revised) and K2 (LCP) are most favourable regarding the percentage reductions in both acidity and nutrient nitrogen critical loads. Of the remaining measures shown, Measures A (Euro low), C (Early Euro low) and N (Shipping) are expected to generate the smaller improvement, with the combined measures (O, P and Q) generating higher reductions than Measure C due to the small incremental benefits from Measures E (LEV) and L (SCP). Combined measure R however produces the highest impact as this package includes both Measures C2 and N.

6.2.2.3 Qualitative assessments

23. For some impacts, it has been concluded that valuation is not possible at this time and neither is it possible to describe the results in terms of quantified impacts. Therefore these impacts are described solely in qualitative terms. It is however possible to provide a guide to the scale and direction of the impact. It is important that the non-valued impacts are taken into account when assessing the different policy options, rather than conclusions being drawn solely from quantified and valued impacts.

24. The impacts which have been presented in a qualitative manner are described below:

- **Social impacts:** The existing evidence linking air quality and distributional (i.e. social and socio-economic) effects has been assessed and used as the basis of a qualitative assessment of the measures (see Chapter 4, section 4.8);

- **Noise:** Chapter 4 also qualitatively considers the impacts on noise of the additional measures. It is expected that noise benefits will be extremely small in relation to other benefits;
- **Competition and impact on small businesses:** Although it has not been practicable to undertake a full, detailed competition assessment as well as an assessment of impacts on small businesses, Chapter 4 presents a qualitative discussion of these impacts; and
- **Additional health impacts:** This section also presents a summary of the major health impacts of pollutants which have been considered qualitatively such as the impacts of the additional measures on benzene and polycyclic aromatic hydrocarbons. These additional health impacts are only expected to be small given that the measures assessed for the review do not aim to tackle the health effects of these additional pollutants.

25. Table 6.2 below presents a brief discussion of these qualitative effects. Only those measures are presented which have significant impacts on two or more of the following impacts: additional health benefits, noise, distribution, competition and small businesses. For example Measure A, which has a moderate impact on distribution, is not presented here as it has a negligible impact on all the other categories. The results for Measure E would also apply to the combined measures O, Q and R; the results for Measure L would also apply to the combined measures P and Q. The qualitative impacts of all the measures are presented in a summarised tabular format in section 6.2.3. A more detailed description of the qualitative impacts can be obtained from Chapter 4 of this report.

26. The assessments of the qualitative impacts are divided into positive and negative although it has not been possible to estimate the impact on the NPV of the measures.

Table 6.2: Qualitative effects of Measures with significant impacts

Measure	Social impact (SI)	Noise (N)	Competition (C)	Small business (SB)	Health impacts (H)
Measure D (Phase out)	Score: **+**	Score: **+**	Score: **N/A**	Score: **N/A**	Score: **+**
	Comments: Wider distributional benefits than other policies, as lower income groups tend to drive older cars	Comments: Reductions in noise, as older cars tend to be more noisy	Comments: Negligible	Comments: Negligible	Comment: Reduction of benzene, 1,3-butadiene leads to a small reduced risk of leukaemia and leukaemia/ lymphoma respectively

Measure	Social impact (SI)	Noise (N)	Competition (C)	Small business (SB)	Health impacts (H)
Measure E (LEVs)	Score: **+**	Score: **+**	Score: **N/A**	Score: **N/A**	Score: **N/A**
	Comments: Possible distribution benefits from improvements in AQ in deprived areas	Comments: Noise benefits may result from this measure	Comments: Negligible	Comments: Negligible	Comments: Negligible or no known effects on benefits for the relevant pollutants
Measure F (Road Pricing)	Score: **+**	Score: **+**	Score: **N/A**	Score: **N/A**	Score: **N/A**
	Comments: Possible distribution benefits from improvements in AQ in deprived areas	Comments: Reductions in noise due to less traffic	Comments: Negligible	Comments: Negligible	Comments: Negligible or no known effects on benefits for the relevant pollutants
Measure G (LEZs)	Score: **+**	Score: **+**	Score: **–**	Score: **–**	Score: **N/A**
	Comments: Possible higher air quality benefits as targeted at urban centres	Comments: Reductions in noise though less than Measure D	Comments: This measure potentially has a negative impact on competition	Comments: This measure potentially has a negative impact on small businesses	Comments: Negligible or no known effects on benefits for the relevant pollutants
Measure I (DomCom Coal)	Score: **+**	Score: **N/A**	Score: **–**	Score: **–**	Score: **+**
	Comments: Strong distributional benefits especially in Northern Ireland	Comments: Negligible	Comments: This measure has a possible negative impact on competitive-ness	Comments: This measure has a possible negative impact on small businesses	Comments: Possibility of small reduced risk for lung cancer due to reduction in PAHs
L (SCP)	Score: **+**	Score: **N/A**	Score: **N/A**	Score: **–**	Score: **N/A**
	Comments: Possible higher air quality benefits as targeted at urban areas	Comments: Negligible	Comments: Negligible	Comments: This measure has a possible negative impact on small businesses	Comments: Negligible or no known effects on benefits for the relevant pollutants

6.2.3 Combined assessment

27. This section presents the combined assessments of all the measures taking into account the quantified assessment as well as the qualitative assessment.

28. The results of the monetary, exceedence, ecosystem and qualitative assessments are presented in Table 6.3 below. There is no attempt to explicitly rank the measures and this table concentrates on presenting the evidence used to assess the measures.

29. However some key conclusions may be drawn from the analysis. For the purpose of brevity and clarity of assessment, only those measures which do not present a negative NPV across the full range of hazard rates are discussed here.

- Measures A (Euro low), C (Early Euro low) generated large net benefits based on the 6% coefficient, for both the no lag and 40 year lag scenarios. These measures also present high positive impacts on exceedences, ecosystems and some possible benefits in terms of distributional effects.
- Measures A2 (Euro revised), B (Euro high), and C2 (Early Euro revised) have the potential to deliver large monetised benefits, assuming a 6% coefficient and no lag for the chronic mortality effect of particles. Assuming a 40 year lag, however, these measures have a (small) negative net present value. These measures presents significant benefits on the ecosystems and exceedence assessment.
- Measure E (LEV) presents positive net benefits as well as having moderately positive impacts on exceedence, noise and distribution.
- Measure K1 (LCP short term) shows positive net benefits, assuming the 6% coefficient and no lag assumptions. Measure K2 also has some benefits in terms of exceedences of current objectives and ecosystem benefits. There are, however, possible negative impacts on competition and security of supply.
- Measures L (SCP) and N (Shipping) present an overall positive benefit cost assessment. The scale of the net benefits from the shipping measure is potentially considerable. Measure N may also deliver ecosystems and exceedence benefits. However, Measure L may have negative impacts in terms of a small business assessment.
- The combined Measures O, P, Q and R deliver significant ecosystem, exceedence and other qualitative benefits. These measures also have the potential to deliver very high net monetary benefits at the top end of the range of possible benefits.

Table 6.3: Summary of the assessments for AQS review additional measures

Measure	NPV £million	Exceedence assessment	Ecosystem assessment	Major qualitative impacts affecting NPV
Measure A (Euro low)	80 – 801	Between 44% and 100% reduction for individual objectives	Significant positive impact	SI+
Measure A2 (Euro revised)	(264) – 539	Between 46% and 100% reduction for individual objectives	Significant positive impact	SI+
Measure B (Euro high)	(432) – 514	Between 62% and 100 % reduction for individual objectives	Significant positive impact	SI+
Measure C (Early Euro low)	148 – 947	Between 47% and 100% reduction for individual objectives	Significant positive impact	SI+
Measure C2 (Early Euro revised)	(246) – 595	Between 48% and 100% reduction for individual objectives	Significant positive impact	SI+
Measure D1 (Phase out)	(4) – (3)	Not modelled	No/insignificant effects	SI+, N+, H+
Measure D2 (Phase out)	(97) – (93)	Between 0.4% and 5% reduction for individual objectives	No/insignificant effects	SI+, N+, H+
Measure E (LEV)	63 – 112	Between 3% and 9% reduction for individual objectives	No/insignificant effects	SI+, N+
Measure F (Road Pricing)	–	Between 3% and 67% reduction for individual objectives	No/insignificant effects	SI+, N+
Measure G1 (LEZs, London Phase I)	(33) – (1)	Not modelled	No/insignificant effects	SI+, N+, C-, SB-

Measure	NPV £million	Exceedence assessment	Ecosystem assessment	Major qualitative impacts affecting NPV
Measure G2 (LEZs, London Phase II)	(67) – (2)	Between 0% and 33% reduction for individual objectives	No/insignificant effects	SI+, N+, C-, SB-
Measure G3 (LEZs, 7 other urban areas)	(14) – (12)		No/insignificant effects	SI+, N+, C-, SB-
Measure H1 (Retrofit – 65%)	(33) – (17)	Not modelled	No/insignificant effects	SI+
Measure H2 (Retrofit – 20%)	(5) – 0	Not modelled	No/insignificant effects	SI+
Measure H3 (Retrofit – 35%)	(7) – 2	Not modelled	No/insignificant effects	SI+
Measure I (Domcom Coal)	(23) – (15)	Not modelled	No/insignificant effects	SI+, C-, SB-, H+
Measure J (Domcom NO_x)	(179) – (148)	Between 0% and 5% reduction for individual objectives	No/insignificant effects	SI+
Measure K1 (LCP)	(107) – 34	Not modelled	No/insignificant effects	C-
Measure K2 (LCP)	(232) – (139)	Between 0% and 15% reduction for individual objectives	Significant positive impact	C-
Measure L (SCP)	18 - 57	Between 0% and 8% reduction for individual objectives	No/insignificant effects	SI+, SB-
Measure M (VOCs)	(249) – (248)	Not modelled	No/insignificant effects	
Measure N (Shipping)	245 – 576	Between 1% and 38% reduction for individual objectives	Significant positive impact	

Measure	NPV £million	Exceedence assessment	Ecosystem assessment	Major qualitative impacts affecting NPV
Measure O (Early Euro low + LEV)	186 – 978	Between 50% and 100% reduction for individual objectives	Significant positive impact	SI+, N+
Measure P (Early Euro low + SCP)	163 – 1,000	Between 52% and 100% reduction for individual objectives	Significant positive impact	SI+, SB-
Measure Q (Early Euro low + LEV + SCP)	203 – 1,053	Between 52% and 100% reduction for individual objectives	Significant positive impact	SI+, N+, SB-
Measure R (Early Euro revised + LEV + Shipping)	33 – 1,211	Between 56% and 100% reduction for individual objectives	Significant positive impact	SI+, N+

Notes:

a This summary shows the lowest and highest expected impact by 2020 (2010 for Measures D and G) on baseline exceedences across all objectives and does not represent a range for individual objectives.

SI represent social impacts which includes impacts on distribution, SI+ implies that the measure has a positive impact on distribution, SI- implies a negative impact.

N represents the impacts on noise, N+ implies a positive impact on noise, N- implies that the measure has a negative noise impact, i.e. due to the measure noise increases

C represents impacts on competitiveness, C+ implies a positive impact and C- represents a possible negative impact

SB represents impacts on small businesses, SB+ implies a positive impact and SB- represents a possible negative impact

H represents qualitative description of the other health impacts these measures may generate, H+ implies a positive health impact. H- implies a possible negative health impact.

6.3 Work going forward

30. The primary focus of the Interdepartmental Group on Costs and Benefits (IGCB) is to undertake the formal economic analysis of the possible impacts of potential future measures that could be implemented to achieve the objectives set out in the Air Quality Strategy. Therefore the further research outlined in this section will focus on improving our understanding on the methodology and assessment techniques of the costs and benefits of air pollution and measures to alleviate them. Further detailed work on improving our understanding on the measuring and quantifying impacts of air pollution can be obtained from Chapter 5 of the Air Quality Strategy review consultation document.

31. Since the publication of the third report we have carried out additional areas of work which were recommended in Chapter 6 of the third report for further consideration:

- A Monte Carlo analysis has been carried out to consider the impact of key assumptions of the overall results of the monetary assessment. The results of this work have been presented in section 5.6 of Chapter 5. This has helped improve our understanding around the impact of the size of hazard rate coefficient for chronic mortality effects, the potential lag time for this effect, uncertainties around cost outturns and the effect of the choice of uplift factor.
- Further work on the possible effects of innovation on technology costs
- Additional work has been carried out to consider the costs of specific measures – namely Measure B – that have the potential for large benefits but currently have high costs. The conclusions from this work, carried out as part of the Monte Carlo analysis, can be found in section 5.6 of Chapter 5.

32. For future research priorities, we recommend in particular, further work on the following, as set out in the Third Report:

- Improving understanding of the appropriate size of the coefficient for the long term effects of particles;
- Improving (if possible) understanding of the types of particles that are driving the long term effects of particles;
- Improving understanding of windows of exposure and lag time to effect for the long term effects of particles;
- Further development of the lifetable methodology e.g. to incorporate the above improvements in understanding;
- Possible long term effects of other pollutants e.g. ozone;
- Development of ways to incorporate effects on respiratory symptoms (including increasing the robustness of the underlying evidence);
- Disentangling (if possible) the separate health effects of nitrogen dioxide and particles;
- Mechanisms of effects of long term exposure including effects of long term exposure on chronic morbidity;

- Damage cost analysis e.g. the incorporation of transboundary effects, the effect of different baseline years on damage cost estimates, disaggregation of ozone damage costs for VOCs and NO_X to differentiate between sector and area;
- Undertake further refinement to the quantification and valuation of the total impact of air quality in the UK;
- Further work on the possible effects of innovation on technology costs, that could substantially reduce the resource costs of the specific technologies used in future measures; and
- Additional work on the costs of specific measures that have the potential for large benefits but currently have high costs (e.g. Measure B) to explore opportunities to reduce these costs.

33. In addition, in light of discussions carried out during the AQS review consultation and the identification of new areas of potential research, we also recommend the further work on the following areas:

34. Further development of the underlying evidence on the impacts of SO_2 on asthmatics through bronchoconstriction and consequently the methodology used to quantifying and value such impacts.

35. Additional work on the impacts of acid and nutrient deposition in habitat areas.

36. Development of ways to incorporate ‘collateral benefits’ or air quality improvements, such as increased fitness and quality of life, into the formal assessment methodology.

37. Further work on quantifying the impacts on ecosystems from air quality.

38. Extending the impact pathway methodology and damage costs to all the pollutants covered by the Air Quality Strategy.

List of abbreviations

$\mu g.m^{-3}$	micrograms per cubic metre
μm	1μm = 1 micron = 1 millionth of a metre
ACS	American Cancer Society
A&E	Accident and Emergency
AQ	Air Quality
AQEG	Air Quality Expert Group – an advisory group that provides the UK Government with independent scientific advice on air quality
AQS	Air Quality Strategy for England, Scotland, Wales and Northern Ireland
AURN	Automatic Urban and Rural Network
B[a]P	Benzo[a]pyrene
BAU	Business as usual scenario (based on the measures already in place)
CAFE	Clean Air for Europe programme, which sets out the European Commission's draft strategy on the future of air quality
CBA	Cost benefit analysis
CHA	Cardiovascular hospital admissions
CO	Carbon monoxide
CO_2	Carbon dioxide
COMEAP	UK Department of Health's Committee on the Medical Effects of Air Pollutants
COPD	Chronic obstructive pulmonary disease
DB[a,l]P	Dibenzo[a,l]pyrene
Defra	Department for Environment, Food and Rural Affairs
DETR	The former Department of the Environment, Transport and the Regions
DoE	The former Department of the Environment
DTI	Department of Trade and Industry
DPF	Diesel Particulate Filter
EAHEAP	UK Department of Health's ad-hoc working group on the Economic Appraisal of the Health Effects of Air Pollution

EPAQS Expert Panel on Air Quality Standards – an advisory group that provides the UK Government with independent scientific advice on air quality, in particular the levels of pollution at which no or minimal health effects are likely to occur.

EQ5D EuroQol 5 Dimensions, a measure of health-related quality of life

Euro(I-VI) European Commission emission standards legislation, relating to Euro standards I to VI for HGVs

Euro(1-6) European Commission emission standards legislation, relating to Euro standards 1 to 6 for LDVs

FBC Fuel Borne Catalyst

GIS Geographic Information System based modelling

GP General Practitioner

HDV Heavy Duty Vehicle (including articulated and rigid heavy goods vehicles)

HEI Health Effects Institute – an independent organisation, based in the US, providing advice on the health effects of air pollution

HGV Heavy Goods Vehicle

HICP Harmonised Index of Consumer Prices

HMT Her Majesty's Treasury

IGCB Interdepartmental Group on Costs and Benefits

IMO International Maritime Organisation

IOM Institute of Occupational Medicine

LCP Large Combustion Plant

LCPD Large Combustion Plant Directive

LDV Light Duty Vehicle (including cars and light goods vehicles)

LEV Low Emission Vehicle

LEZ Low Emission Zone

LGV Light Goods Vehicle (such as commercial vans)

MAAPE UK Department of Health's Advisory Group on the Medical Aspects of Air Pollution Episodes

NAEI National Atmospheric Emissions Inventory

NECD	National Emission Ceilings Directive, which sets national emission ceilings for four pollutants (SO_2, NO_X, VOCs and ammonia)
NH_3	Ammonia
NH_X	Reduced nitrogen compounds (i.e. ammonia (NH_3) and ammonium (NH_4^+))
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_X	Oxides of nitrogen
NPV	Net Present Value
O_3	Ozone
ONS	Office for National Statistics
PAHs	Polycyclic Aromatic Hydrocarbons
PEC	Particulate Elemental Carbon
PM	Particulate matter
PM_{10}	Particulate matter less than 10µm aerodynamic diameter
$PM_{2.5}$	Particulate matter less than 2.5µm aerodynamic diameter
ppb	Parts per billion
PPC	Pollution Prevention and Control Regulations 2000
PPP GNI	Purchasing Power Parity, Gross National Income
Pre-Euro	Vehicles made before the introduction of European legislation on emission limits for new vehicles was introduced
PVR II	Petrol Vapour Recovery Stage II controls
QUARG	Quality of Urban Air Review Group
QUARK	UK Department of Health's sub-group on the Quantification of the Effects of Air Pollution on Health in the United Kingdom
QWB	Quality of Well Being
RHA	Respiratory hospital admissions
RPC	Reduced Pollution Certificate
SCP	Small Combustion Plant

SCPD Small Combustion Plant Directive

SCR Selective Catalytic Reduction

SO_2 Sulphur dioxide

SO_X Oxidised sulphur compounds

UEP12 Department of Trade of Industry's Updated Energy Projections

UNECE United Nations Economic Commission for Europe

VOCs Volatile Organic Compounds

VOLY Mortality impacts based upon a 'value of life year' approach

VOSL Mortality impacts based upon a 'value of statistical life' approach

VPF Value of a Prevented Fatality

WHO World Health Organisation

WTP Willingness to Pay

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Annex 1 – List of IGCB members

The member organisations of the Interdepartmental Group on Costs and Benefits are:

- Department for Environment, Food and Rural Affairs (Defra)
- Department of Health (DH)
- Department for Transport (DfT)
- Department of Trade and Industry (DTI)
- HM Treasury
- Health Protection Agency
- Environment Agency for England and Wales
- Department of Environment for Northern Ireland (DOENI)
- Scottish Environment Protection Agency (SEPA)
- The National Assembly for Wales
- The Scottish Executive

Annex 2 – Valuing the health benefits associated with reductions in air pollution – recommendations for valuation[1]

A2.1 Executive summary[1]

1. The aim of this paper, prepared by the Interdepartmental Group on Costs and Benefits (IGCB), is to explore the most recent valuation evidence on the mortality and morbidity risks associated with reductions in air pollution in order to reach a set of recommendations for valuing these health effects in policy appraisals. Previously in appraisals, when quantifying and valuing the impacts of air pollution on human health, buildings and the environment, Defra has used the methodology developed by the IGCB which is approved across departments. In its most simplistic form, the methodology used to date to value the impacts relies on detailed modelling which converts changes in emissions, to changes in population-weighted concentrations to the number of health impacts (expressed in terms of life years saved, deaths brought forward and hospital admissions). The concentration-response functions used to convert changes in pollutant concentrations to changes in health impacts are derived by the Committee on the Medical Effects of Air Pollutants (COMEAP).

2. The Ad-Hoc Group on the Economic Appraisal of the Health Effects of Air Pollution (EAHEAP) (Department of Health, 1999) investigated whether and which monetary values could then be placed on mortality health endpoints. Due to the lack of empirical evidence on the valuation of these health endpoints, the range of values that EAHEAP could recommend at the time was very large, and hence was not considered appropriate for use in UK appraisals. EAHEAP also recommended that using Willingness To Pay (WTP) was an appropriate method of valuing the impacts of air pollution but that further empirical evidence was required.

3. Consequently, Defra commissioned a study 'Valuation of Health Benefits Associated with Reductions in Air Pollution' (Chilton et al, 2004), to provide empirical evidence of WTP to reduce the health impacts associated with air pollution. Following the publication of the study, Defra held a workshop for expert economists and epidemiologists to discuss the results of this study as well as an EU study, 'The Willingness to Pay for Mortality Risk Reductions: An EU 3-Country Survey' (Markandya et al, 2004) which looked at WTP in the UK for reducing mortality risks associated with air pollution. The recommendations on the valuation of mortality effects associated with air pollution are based on evidence drawn mainly from these two studies, for reasons elaborated in the main text. For the valuation of morbidity effects, the recommendations are drawn from the Chilton et al (2004) study and a study carried out by Pearce et al (1998).

4. There are a number of uncertainties associated both with the evidence on the health effects of air pollution and the application of monetary values to these effects. This paper explores these uncertainties and recommends ways in which they might be overcome or accounted for in policy appraisal. In particular, the paper discusses the uncertainties in:

   - The amount of life expectancy lost due to the acute effects of air pollution;
   - The quality of the life expectancy lost due to the acute effects of air pollution;

[1] This annex was agreed in March 2005 and therefore does not fully take into account the latest COMEAP advice published in its 'Interim Statement on the Quantification of the Effects of Air Pollutants on Health in the UK', (Department of Health, 2006b) and its report on 'Cardiovascular Disease and Air Pollution', (Department of Health, 2006a)

- The ability of respondents to accurately value losses of life expectancy in poor health;
- The accuracy with which respondents valued the morbidity effects; and
- The factors that influence the WTP bids of respondents.

5. Table A2.1 below summarises the recommendations made in this paper. The sensitivities suggested below do not account for all the uncertainties associated with the application of these values. There are still areas of uncertainty that have not yet been resolved due to a lack of conclusive evidence on aspects of both the valuation and the health evidence that underpin some of these recommendations. These recommendations will therefore be reviewed as necessary in light of any further, relevant research.

6. Equally, the health effects below present a subset of all the possible health effects avoided when air pollution is reduced. The reason for this is that there are too many uncertainties involved with quantifying the other impacts on health. The health effects presented below are those that have been recommended by COMEAP for quantification.

Table A2.1: Summary of recommendations

Health Effect	Form of measurement to which the valuations will apply	Valuation – (2004 prices)	
		Central Value	*Sensitivity*
Acute Mortality	**Number of years of life lost due to air pollution (life years)** – assuming 2-6 months loss of life expectancy for every death brought forward. Life expectancy losses assumed to be in poor health.	£15,000	10% and 15% of life years valued at £29,000 instead of £15,000 (to account for avoidance of sudden cardiac deaths in those in apparently good health)
Chronic Mortality	**Number of years of life lost due to air pollution (life years)** – Life expectancy losses assumed to be in normal health.	£29,000	£21,700 – £36,200 (sensitivity around the 95% confidence intervals)
Respiratory Hospital Admissions	**Case of a hospital admission** – of average duration 8 days.	£1,900 – £9,100	£1,900– £9,600
Cardiovascular Hospital Admissions	**Case of a hospital admission** – of average duration 9 days.	£2,000 – £9,200	£2,000 – £9,800

A2.2 Aim

7. The aim of this paper, prepared by the Interdepartmental Group on Costs and Benefits (IGCB), is to explore the most recent valuation evidence on the mortality and morbidity risks associated with reductions in air pollution in order to reach a set of recommendations for valuing these health effects in policy appraisals. The evidence from the valuation studies needs to be considered carefully alongside the evidence on the health effects to ensure that any values recommended for use in appraisal are consistent with the approach to quantification. These recommendations will then form the basis of interdepartmental guidance on valuing the benefits associated with reduced air pollution, which underpins the economic analysis for the Air Quality Strategy.

8. This paper will explore the valuation of mortality and morbidity effects separately. The valuation of mortality effects is explored in sections A2.4 to A2.6 and the valuation of morbidity effects is explored in section A2.7.

9. The valuation evidence on air pollution health effects will be drawn mainly from two recent UK and EU based contingent valuation studies:

   a) 'Valuation of Health Benefits Associated with Reductions in Air Pollution' Chilton et al (2004) commissioned on behalf of Defra; and

   b) 'The Willingness to Pay for Mortality Risk Reductions: An EU 3-Country Survey' Markandya et al (2004) commissioned for the EU NewExt project. This paper will focus on the results of the UK survey.

10. Other studies that value mortality and morbidity have also been considered in a literature review titled 'The Health Benefits of Pollution Control: a review of the literature on mortality and morbidity effects' (Eftec, 2004) carried out for the Health Valuation Workshop held by Defra in June 2004. However, the two studies listed above met most of the necessary criteria set out in the Economic Appraisal of the Health Effects of Air Pollution (Department of Health, 1999) report and considered by the IGCB as being necessary to value correctly the mortality and morbidity effects associated with air pollution. The criteria and rationale for the choice of these valuation studies as the basis for recommending values for use in appraisal is discussed in a later section.

11. The primary focus of the paper is on the valuation of health effects and not the preceding quantification of these health effects in terms of life years lost or deaths brought forward. However, sections A2.5-2.7 provide a summary of the evidence of the air pollution effects on acute and chronic mortality risks and morbidity effects and discuss aspects of that evidence that are of direct relevance to how we apply the valuation figures.

12. There are a number of uncertainties associated both with the evidence on the health effects of air pollution and the application of monetary values to these effects. This paper explores these uncertainties and recommends ways in which they might be overcome or accounted for in policy appraisal.

13. The concluding sections tie in the health evidence with the valuations and recommend practical ways in which the health benefits can be monetised in policy appraisals, taking full account of the associated uncertainties. The recommendations made in this paper are based on the best evidence available at the current time, however, both the evidence on the effects of air pollution on health and the valuation of these effects is constantly evolving and these recommendations will need to be kept under review, and updated to incorporate new evidence when necessary.

A2.3 Background

14. The Air Quality Strategy (AQS) 2000 defines health-based standards and objectives to be achieved for nine key air pollutants between 2003 and 2008. The standards have been set in accordance with the recommendations of the Expert Panel on Air Quality Standards (EPAQS) and the World Health Organisation (WHO) and define concentration levels, which would avoid or reduce risks to health. Objectives have been set with due consideration for what is realistically achievable over a specific time period, taking account of the costs and benefits.

15. The remit of the Interdepartmental Group on Costs and Benefits (IGCB) is to provide the economic analysis, which will support the setting of air quality objectives. The IGCB published an interim report in January 1999. This presented the methodology adopted by the IGCB and preliminary results. A second IGCB Report was published in September 2001 providing the economic analysis to support the review of the AQS objectives for particles.

16. Quantification of the health effects of air pollution in the UK is based on recommendations by the Committee on the Medical Effects of Air Pollutants (COMEAP). COMEAP produced a report in 1998 whose objective was to quantify – as far as possible – the health effects of current air pollution levels in the UK. COMEAP considered all the relevant health evidence available at the time and produced concentration-response functions for four pollutants (PM_{10}, SO_2, NO_2 and ozone) and their associated health effects, which are listed in Table A2.2. The Committee only quantified health outcomes where it was considered that the concentration-response functions could be applied to the UK with reasonable confidence. In 2001, COMEAP published a further report on the long term health effects of particles on mortality (Department of Health, 2001a), which recommended quantification of the chronic mortality effects, but emphasised that there were significant uncertainties to be taken into account. In this report COMEAP considered different levels of reductions in mortality rates due to the long term exposure to particles and commented on their applicability. These reductions in mortality rates are not discussed here and are presented in the Department of Health report (2001a). COMEAP has set up a subgroup to update the 1998 and 2001 reports (Department of Health, 2006b).[2]

[2] The report can be found at http://www.advisorybodies.doh.gov.uk/comeap/pdfs/interimlongtermeffects2006.pdf

Table A2.2: Concentration-response functions recommended by COMEAP

Pollutant	Impact Category	% change in rate per $\mu g.m^{-3}$
PM_{10} SO_2 Ozone	Acute mortality Acute mortality Acute mortality	0.075% 0.060% 0.060%
PM_{10} PM_{10} SO_2 Ozone	Respiratory Hospital Admissions Cardiovascular Hospital Admissions Respiratory Hospital Admissions Respiratory Hospital Admissions	0.080% 0.080% 0.050% 0.070%
NO_2	Sensitivity only[a] Respiratory Hospital Admissions	0.050%

Source: Department of Health (1998; 2001b)

[a] As PM_{10} and NO_2 are highly correlated, there is uncertainty about whether the association between NO_2 and respiratory hospital admissions is due to NO_2 itself or merely an indirect reflection of the effect of particles. For this reason, COMEAP did not recommend use of the association between NO_2 and respiratory hospital admissions in the main analysis.

17. In terms of mortality COMEAP quantifies acute and chronic mortality, and sections A2.5 and A2.6 provide more detail on the evidence regarding these effects. Acute effects are the loss of life expectancy experienced shortly after being exposed to air pollution. The elderly and those in poor health predominantly experience these effects. These effects are quantified in terms of deaths brought forward (DBF). Chronic effects include the loss of life expectancy after being exposed to air pollution for a large amount of time (for example studies have shown that everything else being equal, people in less polluted cities live longer than people in more polluted cities) and are measured in terms of life years lost. In terms of morbidity effects COMEAP quantifies respiratory and cardiovascular hospital admissions and this is explained in further detail in section A2.7.

18. Currently, the process used in policy appraisal to measure the effects of a particular policy to improve air quality is called the impact pathway approach. This approach involves modelling the emission reductions from the relevant emission sources, the associated changes in atmospheric concentrations and population-weighted exposure. These exposure levels are then fed into the dose response functions above, which reveal the physical health impacts of the emission reductions.

19. In order to compare the costs and benefits of meeting the AQS objectives it is important to be able to monetise the quantified health impacts of the objectives. For the economic analysis of the Air Quality Strategy in 2000, the IGCB drew on the advice provided by the Ad-hoc Group on the Economic Appraisal of the Health Effects of Air Pollution (EAHEAP). In particular, the EAHEAP Report provided advice on: (i) how best to reflect the importance of health effects in any cost/benefit decisions in air quality policy; and (ii) whether monetary valuation of health effects was appropriate in the context of air quality, and, if yes, whether any values could be recommended.

20. EAHEAP concluded that monetary valuation was the most appropriate technique to use for the purpose of a full cost benefit analysis and was appropriate for the air pollution context:[3]

    "To compare the costs and benefits directly, the benefits need to be in the same units as the costs. A monetary value for the benefits that reflects the preferences for those at risk can be obtained by finding out what they would be willing to pay to reduce a particular risk. Although reductions in risks are typically not marketable goods, people do pay for measures to reduce risks either directly or through taxation and people do trade off small risks against other things which are important to them. These trade offs can be investigated in carefully designed surveys." [page 2, EAHEAP Report, Department of Health, 1999]

21. EAHEAP went on to note, however, that there were no suitable WTP studies for reduction in air pollution mortality risks in the UK. (Note that since COMEAP only recommended quantification of acute mortality risks at this point, that the EAHEAP group focused only on acute mortality valuation.) The group therefore considered using the WTP studies for reductions in risks of death in the road accident context. However, EAHEAP noted that the road accident WTP results could not be applied directly to the air pollution context without adjustment due to the different nature of risks and characteristics of those affected. The factors that would influence WTP for different risks are illustrated in Table A2.3 below.

[3] EAHEAP also noted that the most fruitful approach in the long run may be a combination of approaches and cross check the results obtained. Monetary valuation most clearly demonstrates whether the benefits exceed the costs but expressing benefits in terms of quality of life and life expectancy would be helpful for comparison with other health interventions.

Table A2.3: Factors that may influence people's WTP for avoiding particular risks.

a) Type of health effect (acute; chronic; latent)	e.g. people may dread a lingering death more than a sudden death
b) Factors related to risk context (such as voluntariness; control; responsibility; uncertainty etc)	e.g. people seem to regard involuntary risks over which they have no control, risks which are someone else's responsibility, and vague risks, as worse than others
c) Futurity of health effect and discounting	e.g. effects which happen sooner are expected to be regarded as worse than those which happen later
d) Age	e.g. people may attach particular value to life and health at certain ages
e) Remaining life expectancy	e.g. WTP is expected to be positively related to the number of years of life expectancy at risk (although not necessarily in direct proportion)
f) Attitudes to risk	e.g. risk aversion is expected to affect willingness to trade wealth for risk; younger people may be less averse to risk
g) State of health-related quality of life	e.g. people are expected to be keener to extend life in good health than life in poor health
h) Level of exposure to risk	e.g. people may be keener to reduce high risk by a set amount than a low risk by the same amount
i) Wealth/income/socio-economic status	e.g. people with more wealth are likely to have a higher WTP to reduce a given risk than those with less, and there may be other differences between social groups.

Source: Department of Health (1999).

22. The adjustments that EAHEAP carried out were based on expert judgment rather than any direct empirical evidence. They adjusted the Department for Transport's Value of a Prevented Fatality (VPF)[4] to account for factors that differed in the air pollution context including:

a) The perceived involuntariness of air pollution risks;

b) The age of the population affected;

c) The life expectancy of those affected; and

d) The quality of life of those affected.

23. The resulting WTP to reduce air pollution acute mortality risks derived by EAHEAP was between £2,600 (for a loss of life expectancy of 1 month and a low quality adjusted life) to £1.4million (for a loss of life expectancy of 12 years with no adjustment for impaired health) in 1999 prices.

[4] Value of Prevented Fatality (VPF) is the same concept as the Value of a Statistical Life (VOSL).

24. Department of Health Ministers considered the results of the EAHEAP group and decided that the currently available data did not allow the benefits to health of reducing air pollution to be converted into monetary terms with a sufficient degree of certainty to allow the results to be used in the cost benefit analysis of the AQS. Therefore the benefits were presented in terms of physical health effects only in the interim IGCB Report and monetised health benefits were presented only for illustrative purposes.

25. A key recommendation of the EAHEAP Report (and the interim IGCB Report) was to undertake empirical studies of WTP for reductions in risk to health in the air pollution context. Based on these EAHEAP recommendations Defra (then DETR) commissioned a study to provide empirical evidence of people's WTP for reducing air pollution mortality and morbidity risks.

26. The study commissioned by Defra was a contingent valuation study conducted in England, Scotland and Wales. The study was entitled 'Valuation of the Health Benefits Associated with Reductions in Air Pollution' (Chilton et al, 2004) and was carried out by a multi-disciplinary team. This study was published in May 2004.

27. Following the publication of the study an expert workshop was held to consider how the results of the Chilton et al (2004) study could be used to value the health benefits accruing from air quality policies in policy appraisal. To place the study's results into context, the results and methodology of this study were compared to those of another contingent valuation study carried out for the European Commission, 'The Willingness to Pay for Mortality Risk Reductions: An EU 3-Country Survey' (Markandya et al, 2004). The use of these studies potentially represents a significant step forward in appraisal methodology as they have provided empirical evidence on WTP to reduce air pollution mortality and morbidity risks in a UK and EU context and evidence on the factors which influence people's WTP decisions.

28. The following sections of this paper describe the results of these two studies and how they can be used to value acute and chronic mortality and morbidity.

A2.4 Valuation of mortality risks

A2.4.1 Rationale for choice of studies

29. The introduction to this paper has highlighted that the valuation evidence for reductions in air pollution mortality risks in the UK will be drawn from two key studies completed in 2004 – the Chilton et al (2004) study and the UK survey in the European Commission study, Markandya et al (2004). EAHEAP (Department of Health, 1999) had previously noted that there was a lack of empirical evidence in the air pollution context. To review this issue and ensure that there is no additional evidence that should be considered, Defra commissioned a Literature Review; 'The Health Benefits of Pollution Control: a review of the literature on mortality and morbidity effects' (Eftec, 2004). This Literature Review was useful in putting the Chilton et al (2004) study and Markandya et al (2004) study into context with other relevant valuation literature on mortality (and morbidity). Table A2.4 below provides a summary of the studies the Eftec literature review covered.

Table A2.4: Recent estimates for the Value of Statistical Life (VOSL)

Study	Country	Type of study	Risk context	VOSL $million (year prices)	VOSL £m (2002)
Costa & Kahn 2002	USA	Wage risk time series	Fatality rates over time	1980: 4.2 – 5.3 (1990)	4 – 5.1
Viscusi & Aldy 2003	USA	Wage risk meta analysis	Various occupational risks	2000: 7.01 (2000)	5.2[2]
Viscusi 2004	USA	Wage risk	Occupational-Industry risk measure	1997: 4.7 (2000)	3.5
Hammitt 2000	USA	Various	Various	1995: 3.0 – 7.0 (1990)	2.8 – 6.6
Alberini et al 2001	USA Canada	Contingent valuation Contingent valuation	Context free reduction in mortality risk between ages of 70 and 80	2000: 1.5 – 4.8 (2000) 2000: 0.9 – 3.7 (2000)	1.2 – 3.6[3] 0.7 – 2.7[3]
Krupnick et al 1999	Japan	Contingent valuation	Context free reduction in mortality risk between ages of 70 and 80	1998: 0.2 – 0.4 (1998)	0.1 – 0.3
Persson et al 2001	Sweden	Contingent valuation	Road traffic risks	1994: 2.64 (1999)	2.0
Markandya et al 2004	UK	Contingent valuation	Context free reduction in mortality risk between ages of 70 and 80	1.2 – 2.8 0.7 – 0.8 0.9 – 1.9 (2004)[4]	0.9 – 2.1 (mean WTP) 0.5 – 0.6 (median WTP) 0.7 – 1.4 (pooled)
Chilton et al 2004	UK	Contingent valuation	Mortality and morbidity impacts from air pollution	0.3 – 1.5 (2004)[4]	0.2 – 1.1
Chilton et al 2002	UK	Contingent valuation	Roads (R), Rail (Ra), Domestic fires (Fd) and public fires (Fp)		Ratios[7]: Ra/R = 1.003 Fd/R = 0.890 Fp/R = 0.960
Beattie et al 1998	UK	Contingent valuation	Roads (R) and domestic fires (F)	5.7 12.8 8.5 (2002)[4]	4.2 (R) for 10^{-5} 9.4 (R) for 10^{-5} 6.3 (F)
Carthy et al 1999	UK	Contingent valuation/ standard gamble	Roads	1.4 – 2.3 (2002)[4]	1.1 – 1.76

Study	Country	Type of study	Risk context	VOSL $million (year prices)	VOSL £m (2002)
Siebert and Wei 1994	UK	Wage Risk	Occupational Risk	13.5 (2002)[4]	9.7
Eliot and Sandy 1996	UK	Wage Risk	Occupational Risk	1996: 1.2 (2000)	0.9
Arabsheibani and Marin 2000	UK	Wage Risk	Occupational Risk	1994: 10.7 (2000)	7.9

Source: EFTEC (2004). 'The Health Benefits of Pollution Control: a review of the literature on mortality and morbidity effects'.

Notes: 1: where relevant. $ values are converted to 2002 UK pounds using PPP GNI per capita ratio between the US and UK and inflated using HICP. £ values from UK studies have been inflated to 2002 prices. 2: median of the studies reviewed, 3: range varies with risk reduction level, lower VOSLs for larger risk reductions. 4: UK £ converted to US$ using PPP GNI per capita ratio between different risk reductions. 5: based on WTP to extend life by one month assuming 40 years of remaining life. 6: based on trimmed means. 7: this study sought respondants' relative valuations of a risk relative to a risk of death from a road accident. Numbers reported here are for the 2000 sample rather than the 1998 sample. Between the two sample periods there was a major rail crash in Paddington

30. As can be seen from Table A2.4 above, the review looked at fifteen studies completed between 1994 and the present day, undertaken in different countries and using a number of different contexts, of which some are contingent valuation studies and some are wage-risk (hedonic price) studies. It is evident from the Eftec (2004) literature review that there is a much larger number of studies that have looked at estimating the Value of a Statistical Life rather than a Value of a Life Year. There are several reasons for this including the fact that most of the VOSL literature is aimed at valuing mortality risks in accident and occupational risk contexts, where large losses of life expectancy are considered. Furthermore, it has only recently been possible to quantify the chronic effects of air pollution. The chronic effects are quantified using cohort studies (explained in more detail in section A2.6.1) which generate changes in life expectancy rather than deaths brought forward. Hence, deriving a monetary value for a life year lost has only recently increased in importance.

31. Provided stated preference studies only are considered, a consensus number of £1 million to £1.2 million emerges for the UK, regardless of the context of the study. However, once wage-risk studies are considered, this consensus in VOSL seems to disappear. Eftec (2004) explains that wage-risk/occupational risk studies tend to yield higher VOSLs as occupational risks tend to be higher than public risks and these studies are based on WTA not WTP (there are reasons for supposing that WTA will be greater than WTP for the same good).

32. Another study relevant to mortality valuation, discussed in Eftec (2004), is a contingent valuation study carried out in Sweden by Johannesson and Johannson (1996). In this contingent valuation study adults are asked their WTP for a new medical programme or technology that would extend expected lifetimes, conditional on having reached the age of 75. Respondents are told that on reaching 75 they can expect to live for another 10 years. They are then asked their WTP to extend their lifetime from 10 years to 11 years beyond 75, i.e. the value of one extra year.

33. The results from the Swedish study suggest average WTP across the age groups of slightly less than 10,000 SEK using standard estimation procedures and 4,000 SEK using a more conservative approach. In 2002 pound sterling terms, these figures work out as £400-£1,000 for a one year increases in expected life. Johannesson and Johansson suggest these values are consistent with VOSLs of £19,000 to £69,000, substantially less than other VOSLs reported in the literature. The authors conclude that the main reasons for the significantly lower WTP for extending life expectancy is the low expected quality of life by the respondents. Indeed, another study carried out by Johannesson and Johansson (1997) which tried to measure the expected quality of life at an advanced age, found that, relative to studies estimating actual quality of life at an advanced age, the average quality of life expected by respondents was much lower.

34. The EAHEAP report highlighted that the Johannesson and Johannson (1997) study appeared to provide a good approach for valuing gains in quality adjusted life-years (Department of Health, 1999). However, they conclude that it would have been difficult for respondents to give an accurate response to the WTP question at hand, as for the average respondent in the study the life-year extension would have been 44 years away, and hence did not use its results directly to inform policy appraisal.

35. For the purposes of making recommendations for mortality valuations to use for the air quality context, in policy appraisal in the UK, it was not appropriate to consider in detail the results of all the studies covered in the Eftec review. Hence, the most appropriate studies needed to be selected. The EAHEAP report, after concluding that monetary valuation was the most appropriate way to consider the costs and benefits of air quality policies, made several suggestions on what type of empirical evidence would be most useful in valuing the health benefits from reducing air pollution. The report also concluded that it was not appropriate to apply empirical evidence on monetary valuation of the reduction in risks of death from other contexts, such as the road accident context, without adjustment to the air quality context. This report suggested that further research be carried out on monetary valuation of the health benefits. For valuing mortality, EAHEAP recommended work on the following:

WTP to reduce the risk of a death brought forward by air pollution;

- The valuation of chronic effects;
- The different factors influencing WTP;
- The relationship between WTP and quality of life; and
- People's attitudes to air pollution risks.

36. The methodology used to quantify the mortality effects associated with air pollution generates life years lost and deaths bought forward (this is explained in more detail in sections A2.5 and A2.6). It is therefore also important to have studies that generate both VOSLs and VOLYs. Furthermore, it is clear from Eftec (2004), that the country in which the study is carried out has a significant effect on the resulting figures of WTP. It was therefore concluded that the recommendations for use of values in UK appraisal should be mainly based on studies that were carried out in the UK.

37. In order to decide which papers to consider in detail the IGCB decided to narrow down the number of studies according to whether they had the following characteristics:

- The study was based in the UK using a representative UK sample of respondents;
- The study used an air pollution context;
- The study elicited people's WTP to reduce the risk of their death brought forward by air pollution; and
- The study also estimated the value of a life year, which could be applied to the quantified health effects expressed in terms of life years lost.

38. Although there are a number of wage-risk studies and contingent valuation studies that elicit people's WTP for mortality risks, the only two studies that specifically try and value mortality risks associated with air pollution in the UK are the Chilton et al (2004) and Markandya et al (2004) studies. The Chilton et al (2004) study meets all the criteria set out above although the Markandya et al (2004) study is context free. However, the intended purpose of the Markandya et al (2004) study is to value mortality associated with air pollution, so more detailed consideration is given to its results in this paper. Hence, these two studies are described below and their results used to inform the policy recommendations.

A2.4.2 Chilton et al (2004) and Markandya et al (2004) studies.

A2.4.2.1 The Chilton et al (2004) Study

39. The study commissioned by Defra 'Valuation of Health Benefits Associated with Reductions in Air Pollution' is a contingent valuation study, that specifically focused on an air pollution context, and elicited household WTP for reducing the risks of four adverse health effects of air pollution:

- Chronic mortality – the impact on life expectancy of long term exposure to average levels of pollutants in the air – these life expectancy losses occur in good health (Good N);
- Acute mortality – the deaths brought forward (particularly among those in poor health) by episodes of high pollution (Good P);
- Emergency admissions to hospital occasioned by such episodes (Good H); and
- Days of breathing discomfort caused or aggravated by raised levels of pollution (Good D).

40. A summary of the methodology and key results of the study are provided below. The first stage of the survey asked respondents to consider a number of public health risks and rank them. They were then told that the study was specific to air pollution and given a number of ways in which air pollution might affect people's health (see Table A2.5 below from the Chilton et al (2004) study). Respondents were also asked whether they or anyone else in their household had any personal experience with breathing discomfort or admission to hospital with breathing difficulties.

Table A2.5: Mortality and morbidity impacts of air pollution on health

CHRONIC MORTALITY	ACUTE MORTALITY
"FASTER AGEING. Some chemicals in the air may cause wear and tear on our bodies, so that people living in areas with more pollution may age faster and die younger than people in low pollution areas. Some experts think that the average person in Britain might lose about a month of life in this way. Others think the average loss of life might be as much as a year."	"DEATH BROUGHT FORWARD WHEN ELDERLY AND IN POOR HEALTH. On a few days every year, air pollution reaches unusually high levels. For some people in their 70's and 80's with existing heart or lung disease, the unusually high level of pollution on a bad air day can put so much extra stress on their breathing that their heart fails and they cannot be revived. Often these people are not expected to live very much longer anyway, but a bad air day can bring their death forward. If the bad air day had not occurred, they could have lived a few weeks or months longer, although this time would have been spent in their existing poor state of health."

RESPIRATORY HOSPITAL ADMISSION	DAYS OF BREATHING DISCOMFORT
"HOSPITAL ADMISSION. Another possible effect of bad air days is that some people need hospital treatment. The people affected in this way are mostly in their 70's and 80's with some kind of lung disease, although some of those affected may be younger people with asthma or other chest conditions. The unusually high pollution can cause them to suffer an attack of coughing, wheezing, chest pains and struggling for breath which becomes so bad that they need to be admitted to hospital. They may have to stay in hospital for anything from a day or two, up to a couple of weeks, followed by a period of time resting at home."	"BREATHING DISCOMFORT ON 2 OR 3 DAYS EVERY YEAR. For people of all ages who have asthma or various other allergies or chest conditions, bad air days can bring on a cough and a feeling of discomfort in the chest. If they do any heavy work or vigorous activity they may wheeze or feel breathless. As soon as the bad air day is over, they return to normal health. But, on average, they are likely to suffer 2 or 3 days of breathing discomfort every year throughout their lives."
Source: Chilton et al (2004).	

41. The rest of the survey/questionnaire focused on eliciting willingness to pay (WTP) for four possible benefits presented in Table A2.6 below. For each of the benefits in turn, respondents were asked to think about how much benefit, if any, it would be to their household on a qualitative scale from "no benefit at all" to "a very big benefit". Before answering any WTP questions respondents were asked to consider their budget constraints and disposable income. It was explained that there were several ways to reduce air pollution but the cost of these measures would be likely to increase prices of all kinds of everyday goods and therefore increase the cost of living for their household. Having considered their household finances, respondents were then reminded of the benefit ratings they had given to each of the four scenarios described above. Each respondent was then asked first of all whether they would be willing to pay anything at all in the form of higher prices for any of these four benefits.

Table A2.6: The four benefits of reducing air pollution valued by respondents

N (Chronic Mortality)	P (Acute Mortality)
"X MONTHS MORE LIFE IN NORMAL HEALTH. By reducing the general level of air pollution that causes wear and tear and faster ageing, everyone could live longer. That would mean that you (and everyone else in your household) could expect to live about X months longer in your (their) normal state of health."	"X MONTHS MORE LIFE IN POOR HEALTH WHEN ELDERLY. This would be most likely to benefit elderly people with heart or lung disease. By reducing the number of bad air days, such people could expect to live about X months longer, although this extra time would be spent in their existing poor state of health."
H (Respiratory Hospital Admission)	**D (Days of Breathing Discomfort)**
"AVOIDING AN ADMISSION TO HOSPITAL WITH BREATHING DIFFICULTIES. This would be most likely to benefit people in their 70's and 80's who have some kind of lung disease, or younger people with asthma or other chest conditions. By reducing the number of bad air days, such people would be less likely to develop attacks of breathing difficulties which require admission to hospital."	"AVOIDING 2 OR 3 DAYS OF BREATHING DISCOMFORT *EVERY YEAR*. This would be most likely to benefit people with asthma or various other allergies or chest conditions for whom bad air days can bring on coughing and wheezing. By reducing the number of bad air days, such people would avoid 2 or 3 days of breathing discomfort like this every year from now on."
Source: Chilton et al (2004).	

42. Those respondents who agreed to pay something then embarked on a random card sorting procedure. They were shown different cards bearing different amounts and asked to identify the most they were willing to pay each year for the rest of their lives to get all four of the benefits. They were then asked to divide their total WTP between the four benefits. In the case of life expectancy extended in poor and normal health, the amount of life expectancy respondents were asked about was randomly set at 1, 3 or 6 months as a sensitivity to scope. Respondents were asked to consider how much they were willing to pay to obtain all those benefits for their household, as budget decisions are usually taken at this level and it is difficult to separate it out on an individual level.

43. Krupnick et al (2004) noted that the Chilton et al study asked respondents their WTP for improvements in life expectancy, even though air pollution is a public good. Respondent's bids for public goods tend to be higher than their bids for private goods. Krupnick therefore implies the WTP results in this study could be under-estimated, although it is not possible to assume anything about the level of underestimation.

A2.4.2.2 Results

44. For the purpose of the Chilton et al (2004) survey, 665 interviews were completed of which 138 were categorised as protest votes and hence not included in the final analysis. The total sample was split into three sub-samples who were asked to value different lengths of life expectancy in normal and poor health; 1 month, 3 months and 6 months. Although having three sub-samples allowed for the testing of sensitivity to scope, it did mean that each sample was quite small (ranging from 228 people to 214). The summary statistics showed that the distribution of responses was positively skewed and that there were some extreme outliers exerting an unduly strong influence on the mean responses. Consequently, the study also presents trimmed means, with the four largest and four smallest values trimmed from the datasets, and uses these in the policy conclusions of the study.

45. When the mean WTP values were considered, the household WTP amounts were significantly higher for Good N than for Good P, indicating that respondents valued a gain of life expectancy in normal health more highly than a gain life expectancy in poor health. The authors however, highlight that one possible reservation about this result is that respondents were asked to value the certainty of receiving extra life in normal health as opposed to the chance of extra life in poor health. If respondents were considering the gains in life expectancy in poor health as a certainty then Good P is indeed valued less than Good N. However, if the likelihood of receiving Good P was considered then it is possible that respondents did not value Good P significantly less than Good N. This issue was explored further in the statistical analysis and qualitative interviews.

46. Detailed statistical analysis was carried out relating WTP for each of the four benefits to a range of variables that might be thought to influence WTP. The statistical analysis is important in the context of this paper as it gives some confidence that WTP varies in the way theory would predict with changes in particular variables. The results of the regression analysis are summarised here but can be found in a lot more detail in the report. The statistical analysis carried out on the data showed that WTP for increases

in life expectancy in normal health was positively affected by the number of months of life expectancy being considered, per capita income and household size. This fits with what we might expect from theory, which is encouraging. Moreover, variables such as "start card" were not significant which is consistent with a priori expectations. The results also showed that WTP of respondents falls as respondent's age increases.[5] WTP does increase as the size of the life expectancy benefit increases, indicating some sensitivity to scope. However, that sensitivity is limited as the WTP for gains in life expectancy does not increase in proportion with the size of the gain.

47. In the case of WTP for extending life in poor health (WTP-P), neither the number of months nor the level of income have any significant impact. The authors note this suggests an ambivalence among respondents about whether extending their lives in such poor health was indeed a benefit. The strongest relationship appeared to be that WTP–P is inversely related to age, possibly reflecting a greater aversion among older people of having their life extended in poor health. It is also important to note the relationship between WTP-P and 'likelihood of benefiting' was positive and significant implying that not all respondents were treating these goods as if they were certain benefits.

48. The study team also undertook a number of qualitative interviews (although the sample was not representative of the UK population). The main results from these qualitative interviews were:

    - The main factor determining respondents WTP was their view of what they could afford;
    - The information about the lifetime total payment was largely ignored (which suggests that estimates of values should be derived from the annual amounts) and there was also very little or no evidence that respondents thought of the benefits being worth some lump-sum amount;
    - Not all respondents were considering the likelihood of them experiencing P and a proportion were directly comparing increased life expectancy in normal health with the certainty of increased life expectancy in poor health; and
    - There is no evidence to suggest that gains in life expectancy in good health from reducing air pollution should be valued significantly differently from similar gains produced by improved road safety.

49. In their analysis of the data for policy implications, the authors put forward the case for using the 1 month values as they believe that the 1 month values are less likely to be perceived as non-marginal and hence are less likely to hit respondent's budget constraints. In addition, based on current epidemiological evidence, policy measures are also more likely to generate life expectancy increases in magnitude of a month (or less for short term effects) rather than three or six months.

[5] There were no strong priors about the impact of age on WTP. Since respondents were asked to answer on behalf of their household, the respondent's own age might be expected not to matter.

50. Following the analysis of the WTP and qualitative responses the study team made recommendations on how to use the evidence they collected in policy appraisals. Firstly, the trimmed annual mean household WTP was converted into a per person annual WTP[6] for an increase in life expectancy in normal health of 1, 3 and 6 months (these figures are illustrated in the second row of Table A2.7). Secondly, the study team took the per person, annual, trimmed mean of WTP for extended life expectancy in normal health, from their cross-section of households (£29.52) and multiplied it by the life expectancy of the average person (i.e. 78 years),[7] to arrive at a lump-sum figure per person over their lifetime of £2,302 for a 1 month gain in life expectancy in normal health. Table A2.7, row 3 also illustrates the annual WTP for one year increase in life expectancy, derived by multiplying the WTP for a 1 month gain in life expectancy by 12.

51. For policy appraisal purposes it is desirable to have a standard unit such as the Value of a Life Year (VOLY) or the Value of Statistical Life (VOSL) which are used in the quantification of health benefits. To arrive at 'the value of a year's increase in aggregate life expectancy' the authors suggested that such a year could be achieved by adding 12 individual's lifetime WTP (£2,302) for a month's increase in life expectancy. Following this through, the study generates a VOLY of £27,630 for a year's increase in life expectancy in normal health. The 95% confidence intervals around this value are £20,690 – £34,440 (2002 prices). The results from the 1, 3 and 6 month sample for normal health are illustrated in the 4th row of Table A2.7.

Table A2.7: Chilton et al (2004) study values for increases in life expectancy in normal health – Good N (2002 prices)[8]

	1 Month Sample	3 Month Sample	6 Month Sample
Annual WTP (per person)	£29.52 (31)	£30.21 (31.74)	£38.73 (40.7)
Annual WTP for one year gain (per person)	£354 (£372)	£121 (127)	£78 (82)
Total value of one life year	£27,630 (29,030)	£9,430 (9,907)	£6,040 (6,346)
VOSL (x 40 yrs)	£1.11m (1.2 million)	£377,200 (396,296)	£241,600 (253,831)

52. The Chilton et al results are derived without using any discounting. The authors explain that the evidence from their study suggests that 'people were giving responses in terms of their current real value for money, with those respondents presenting a cross-section of the population involving people at every stage of their lives' (Chilton et al 2004). Consequently the authors explain that they see no reason why they should discount WTP to account for diminishing marginal utility of income (as previous empirical evidence has shown that WTP-based values of safety and longevity grow in

[6] The household WTP was converted to an individual WTP by the following formula: (household mean x total number of households)/ total number of individuals. The individual results are used in the policy recommendations.

[7] The authors explain that: '78 years is the mean period of time over which the benefit of a reduction in air pollution will be enjoyed by anyone born after the reduction is effected'. However, other adjustments might need to be made if we restrict attention to the population alive at the time of introduction of the air pollution improvement or for other planning horizons.

[8] Numbers in brackets are the values converted to 2004 prices assuming an inflation rate of 2.5%.

line with per capita real income) nor to take account of pure utility discounting (as it can be thought of as ethically indefensible). For these reasons and reasons of simplicity Chilton et al report their results without undertaking any discounting.[9]

53. The study also concludes that 'There is no strong evidence from the present study for using a figure which is either significantly higher, or else significantly lower, than the road safety value. Indeed if the VOLY derived from this study is multiplied by 40 years (the average loss of life expectancy from road accidents) the derived VOSL is £1.105 million which is very close to the VOSL used by DfT for the road accident context.

54. The authors use the same approach (as described in paragraphs 49 and 50) to derive a value of a life year in poor health (acute effects). Table A2.8 below lists the results. The results in the first three rows of Table A2.8 assume that respondents regarded the benefit as a certainty for all household members. Although the qualitative interviews support this assumption, the regression analysis indicated that some respondents might have been considering the likelihood of the benefit occurring. Hence, the authors investigated how WTP for Good P would change if allowance was made for respondent's judgements of the likelihood of experiencing that benefit. The figure listed in the last row of Table A2.8 illustrates the maximum impact such adjustments could have on the VOLY for poor health.

Table A2.8: Chilton et al (2004) study values for increases in life expectancy in poor health – Good P (2002 prices)[10]

	1 Month Sample	3 Month Sample	6 Month Sample
Annual WTP (per person)	£7.78 (8.17)	£5.14 (5.4)	£8.29 (8.71)
Annual WTP for one year (per person)	£93 (97.7)	£21 (22)	£17 (17.86)
Value of one life year (VOLY)	£7,280 (7,649)	£1,600 (1,681)	£1,290 (1,355)
Likelihood adjusted VOLY	£14,280 (15,003)	–	–

A2.4.2.3 Markandya et al (2004) Study

55. The Markandya et al (2004) study is an application of a survey design used by Krupnick et al (2002) in a previous survey in the USA, Canada and Japan, and is carried out in Italy, France and the UK. For the purposes of this paper the focus will be on the results of the UK survey only.

9 This does not preclude the use of discounting when these values are used in policy appraisal.

10 Numbers in brackets are the values converted to 2004 prices assuming an inflation rate of 2.5%.

56. The respondents to the UK survey were recruited from an area within 35km from Bath. The sample size was 330 and respondents ages were 40 years and older. The survey consisted of several stages including: establishment of the health state of respondents; respondents are educated about probabilities in general and about mortality risks; generating the baseline risk of respondents based on their age and gender; respondents are informed of age and gender specific causes of death and common risk-mitigating behaviour; and the elicitation of WTP for risk reductions of a given magnitude. The elicitation format was dichotomous choice with two follow-up questions and involved respondents using tele-visual screens and administering the survey themselves.

57. Respondents were asked for the WTP for a new product that reduces their chance of dying from a disease or illness (no context is specified). They were told the product would reduce their chance of dying over the next ten years by some magnitude of risk change. Respondents are reminded that they would have to pay the full cost of this product 'out of their own pocket' and that that would leave them with less money to spend on other things.

58. The 'goods' in question are (a) reductions in (immediately effective) mortality risk over a period of ten years, and (b) reductions in the probability of death between the ages of 70 and 80. Two immediate risk reductions are posited: a 5 in 1000 reduction over a period of 10 years, and 1 in 1000 reduction over a period of 10 years. For the second good, respondents aged 60 or under are asked their willingness to pay for a 5 in 1000 reduction in the risk of dying that begins at age 70 and ends at age 80. (Respondents are reminded they may not live to 70). Following the elicitation of WTP values, respondents are debriefed to gain insight into their decision process and help explain potential variations in WTP.

59. The authors explain their choice of risk reduction x in 1000 as their basic unit of risk communication as follows: 'This unit was chosen following extensive testing in North America. It was concluded that the use of grids with more than 1,000 squares (i.e. 10,000 or 100,000) results in reduced cognition and a tendency to ignore small risk changes as being insignificant. Because annual risk changes associated with air pollution policy are smaller than 1 in 1000, however, the commodity is expressed as a risk change over 10 years totalling x per 1,000. Baseline risks and payment schedules are also put in 10-year terms'. The authors go on to explain that their survey discusses mortality in 10-year intervals as pre-testing of the survey showed that respondents found it a lot easier to conceptualise the possibility of dying in a 10-year period than over a 1-year period. Furthermore, the 1 in 1,000 risk change over a 10 year period is implicitly approximately 1 in 10000 risk change a year, which is in the appropriate range for capturing the risk reductions associated with air quality improvements (per person affected, rather than when averaged across the whole population).

A2.4.2.4 Results

60. Most of the analysis on the results is focussed on the 5 in 1000 immediate risk reduction, as the authors considered it to be more reliable than the 1 in 1000 risk reduction, which could have been to too small for the respondents to comprehend with precision.

61. When performing a regression analysis on their survey results for the 5 in 1000 immediate risk reduction the authors found the following factors influencing respondents' WTP:

- There was no meaningful association between respondent age, baseline risk nor remaining life expectancy and WTP.
- Income per household member was positively and significantly associated with WTP.
- Higher education levels were associated with lower WTP.
- In general the health status did not affect WTP other than the variable that controls for the respondent having a chronic heart or lung condition which was positive and significant.
- WTP for the future risk reduction tended to increase with the logarithmic chance of surviving to age 70 and to fall if respondents thought their health would be worse in the future.

62. In terms of sensitivity to scope, the WTP results pass the internal scope test, but the evidence on proportionality is varied. Only median WTP passes the proportionality test whereas mean WTP answers do not change proportionally with the change in magnitude of the risk.

63. The Markandya et al (2004) study generates VOSLs. However, they acknowledge that recent epidemiological evidence generates changes in life expectancy, or life years lost. They use a procedure produced in Rabl (2002, quoted in Markandya et al 2004) which enables mortality risks to be translated into losses of life years. Using the Rabl procedure, they estimate that 'a person of 55 (the average age of respondents to the survey) will gain an equivalent of 40 days from a 5 in 1000 risk reduction' (the other risk changes are not analysed). The resulting VOSLs and VOLYs from the UK survey are listed in Table A2.9.

Table A2.9: Markandya et al (2004) values for changes in risk reductions[11] (2002 prices) – UK results

	VPF (VOSL)	VOLY
Immediate 5 in 1000 risk change (mean)	£0.92 million (0.97 million)	£41,975 (44,100)
Immediate 1 in 1000 risk change (mean)	£2.07 million (2.17 million)	£94,334 (99,110)
Future 5 in 1000 risk change at 70-80 (mean)	£377,880 (397,010)	£17,241 (18,114)

[11] The values in Table A2.9 are based on the UK survey results and not the 3-country wide results. Numbers in brackets are the values converted to 2004 prices assuming an inflation rate of 2.5%.

64. Although the main survey did not directly elicit VOLYs (because previous work had shown that VOLYs were too difficult for respondents to comprehend), Krupnick et al (2004) mentions that the team (headed by Brigitte Desaigues) that carried out the French part of the survey did include questions eliciting WTP for life expectancy improvements. The results generated a VOLY ranging from €20,000 to €220,000, depending on the basis for the scaling to a life year (i.e. whether one month or six months life expectancy was being considered). Although Krupnick et al (2004) points out that these results were based on a very small sample and that there were other problems with the survey and hence are not representative, they perhaps increase confidence in the both the Chilton et al and UK Markandya et al VOLYs, which all fall within this range.

A2.4.3 Conclusions from the Defra workshop

65. The workshop focussed on the valuation of acute effects associated with air pollution and did not discuss morbidity. Furthermore, much of the discussion at the workshop centred on the valuation of mortality risks and life year gains occurring in people in the 'normal' health scenario. One of the main conclusions from the Defra workshop was that there is some support for the results of the two valuation studies because the resulting VOSLs were very similar, and close to VOSLs used in other contexts.[12] The qualitative interviews carried out in the Chilton et al (2004) study, although based on an unrepresentative sample, also support the view that respondents did not perceive accident contexts as being very different to pollution risk contexts. As Pearce (2004) indicates in his rapporteur's note, some caution about this conclusion was raised due to two main issues: (a) the failure of both studies to the strict proportionality scope test; and (b) prior expectations, as illustrated in Table A2.3, as to why pollution values should differ from accident values.

66. Other issues that were raised at the workshop were the extent to which contingent valuation studies in general over-state people's true values as respondents are never fully in the position to relate their WTP values to the whole array of alternative public goods they can afford. The link between age and WTP was also discussed but no consensus was reached amongst the delegates at the workshop as the Chilton et al (2004) study showed WTP declining with age whereas other studies, including the Markandya et al (2004) study, have shown no relationship between age and WTP.

67. In his presentation, Brett Day also raised the issue of whether the two studies were valuing similar 'goods', and hence whether they were comparable or not. The Chilton et al (2004) study generates values for changes in life expectancy as opposed to changes in mortality risks, as in the Markandya et al study. Furthermore, the time period over which the good will be experienced also differs between the two studies with the Chilton et al (2004) study valuing future loses in life expectancy and Markandya et al (2004) valuing both immediate and future risk reductions. How probabilities of death are linked to life expectancy changes was also discussed, as the Markandya et al study uses a specific formula to convert risks of death to changes in life expectancy. It was decided that this type of procedure needs further investigation as it would facilitate the conversion between VOSLs and VOLYs and vice versa.

[12] For example, the DfT VOSL which is used in the risk-accident context and is equal to £1.25 million.

68. The workshop did not resolve all of these issues but overall, the discussants felt that there was more evidence in support of the two studies than there were problems with them and for the use of these values in appraisal.

A2.5 Valuing acute health effects

A2.5.1 Health evidence on the acute effects

69. The following section outlines the relevant health evidence on the acute effects associated with air pollution and provides guidance on how the existing monetary values can be applied to the physical effects.

70. Information on the acute effects of air pollution is derived from time-series studies. These are studies that relate particular daily levels of air pollution to health outcomes on the same day, the following day or days shortly afterwards.

71. For mortality, the results simply indicate that, as the daily level of air pollution increases, numbers of deaths also increase. The results are based on routinely collected death statistics, so the studies themselves do not contain any information on the characteristics of the people who have died. However, the characteristics of the people who have died may influence the monetary value people would be willing to pay to avoid (or, more strictly, defer) these deaths. Some of the information from other sources that can be used to infer what these characteristics might be are discussed below. Paragraphs 72 to 74 consider the possible length of life lost as a result of a death brought forward. As this is inferred indirectly, a number of authors have given various estimates which are described below. Paragraphs 75 to 79 consider whether the life lost would have been in good health or poor health.

72. COMEAP consider that the deaths are likely to occur in patients with severe pre-existing disease (Department of Health, 1998). This is based on clinical judgement – for example, patients with chronic obstructive pulmonary disease (COPD) are usually ill for some years prior to their deaths and have become increasingly seriously ill over time. It was also judged that, as the patients affected were already seriously ill, the loss of life expectancy that might occur as a result of air pollution bringing patients' deaths forward would be quite small. Around 23% of moderately ill COPD patients die within 3 years (Anthonisen et al, 1986). COMEAP suggested an average loss of life expectancy of 2 to 6 months (Department of Health, 2001a).

73. There have been two developments since the 1998 report of relevance to this issue. One is the use of new statistical techniques to determine changes in deaths not only on the following one or two days after a particular bad air pollution day but also to changes to numbers of deaths around 40 days later. It was found that there were still increases in deaths – and indeed larger ones – at these longer time lags (Schwartz, 2000; Brunekreef and Hoek, 2000; Zeger et al, 1999; Samet et al, 2000; Dominici et al, 2003; Zanobetti et al, 2003). This means that most of the deaths brought forward by particles must involve losses of life expectancy greater than a few days (if all the susceptible people were due to die anyway within a few days, it would not be possible to show increases in deaths on a timescale of weeks). In addition, greater losses of life expectancy cannot be ruled out. The technique could not be used to identify whether

displacement of deaths was more than 40 days because the interpretation of any increases in deaths at longer lags would be confused by the variation in deaths that occurs by season (for example, deaths are always higher in the winter). The techniques therefore cannot determine one way or the other whether a particular day's air pollution is associated with changes in deaths into the next season. Nevertheless, the fact that the pollution effects increased as lag increased led the authors to conclude that displacement was probably considerably longer than 40 days. An editorial discussing some of these studies (Brunekreef and Hoek, 2000) suggested that some of the deaths were brought forward 'by at least 2 months'.

74. Although various estimates have been made, they are all of a few months or more. The COMEAP estimate of around 2 to 6 months therefore seems a reasonable range to use, with an acknowledgement that greater losses of life expectancy are possible.

75. The other development is the increasing evidence of an effect of air pollution on heart disease (Department of Health, 2006a). As mentioned in an earlier paragraph, it is not generally expected that deaths from respiratory disease occur in people who were not already ill. However, for cardiovascular disease, it is known that some deaths occur suddenly in people who are apparently healthy i.e. people who have a disease but no symptoms. Although, it does not necessarily follow that these people would have remained apparently healthy if the cardiovascular death had not occurred at that time, there is a possibility of significant gains in healthy life expectancy occurring if these sudden deaths could be deferred. The question is what proportion of the deaths brought forward by air pollution could come into this 'sudden cardiac death' category? It should be acknowledged that this question is very difficult to answer. Time series studies use routine statistics, which do not include information about the patient's characteristics prior to death. 'Sudden cardiac death' is not a certifiable cause of death so it would be unclear from the death certificate whether the death was unexpected or not. It should also be acknowledged that sudden cardiac death could occur in a young person with a severe single coronary stenosis, which would be amenable to life saving surgery giving a very considerable life gain, or in an old person with multi-vessel, inoperable coronary disease whose life expectancy was very short.

76. The 1998 Quantification Report chose to quantify all cause mortality as this avoids the issue of misclassification of the cause of death. So there are no recommended exposure-response functions for respiratory and cardiovascular mortality separately in the COMEAP report. Results from the APHEA I study (Zmirou et al, 1998) suggest that particles, sulphur dioxide and ozone are associated with lower percentage increases in cardiovascular deaths than for respiratory deaths. However, as discussed in the EAHEAP report, the baseline numbers of cardiovascular deaths are around 1.8 times[13] higher than the numbers of respiratory deaths. Thus, overall the numbers of cardiovascular deaths may exceed the number of respiratory deaths (see Box A2.4 at the end of this annex).

[13] This number can vary somewhat from year to year. EAHEAP used 1998 statistics. Box 2.4, at the end of this annex, uses 2003 statistics and finds relatively higher numbers of cardiovascular deaths.

77. 'Cardiovascular' deaths include deaths from heart disease (cardiac deaths) and deaths from other circulatory diseases such as stroke. There is some indication (Department of Health, 2006a) that air pollution has more of an effect on cardiac deaths than deaths from stroke. However, it is less well established which types of cardiac deaths are most affected. Sudden cardiac deaths can arise as a result of ischaemic heart disease where the coronary blood vessels become blocked and deprive the heart muscle of oxygen or as a result of arrhythmias (disruption of the heart's rhythm) (which may themselves be the result of ischaemic heart disease). There is some evidence that air pollution is associated with deaths occurring via both of these mechanisms (Department of Health, 2006a), although this evidence does not distinguish whether the deaths were in people who did or did not know that they had heart disease. There are very few studies examining air pollution and sudden deaths directly. One study (Levy et al, 2001) found that particles were not associated with sudden death in people without clinical heart disease. A pilot study by Peters et al (2000) found that discharges of implanted cardioverter defibrillators were associated with increases in nitrogen dioxide, $PM_{2.5}$ and carbon monoxide. Although these patients were of course aware that they already had heart disease, this study does suggest that air pollution may be associated with life-threatening arrhythmias, one of the causes of sudden cardiac death. However, it should be noted that patients with implanted cardioverter defibrillators are a tiny subset of heart disease patients. Sudden cardiac deaths can occur in many other types of heart disease patients.

78. As the evidence as to which types of cardiac deaths are most affected is not conclusive, it may be helpful as a general guide to assume that the distribution is similar to the baseline distribution of the different types of cardiac deaths. In the United States, it has been estimated that sudden cardiac arrest accounts for half of all deaths that are due to cardiovascular disease (Callans, 2004; Virmani et al 2001; Wannamethee et al, 1995) and that cardiac arrest is the first manifestation of an underlying problem in 50 percent of patients (Callans 2004; Wannamethee et al 1995). This implies that around 25% of all cardiovascular deaths are sudden deaths with no previous knowledge of an underlying problem. Care needs to be taken with these figures as definitions of sudden cardiac death vary (Virmani et al 2001). In England, a study of sudden death in subjects aged 16 to 64 with no previous history of heart disease estimated a rate for sudden unexpected cardiac adult death of 11 per 100,000 (Bowker et al, 2003). This is about 14% of the rate for all cardiovascular deaths in the 16 to 64 year age group (around 75 per 100,000 (Office for National Statistics, 1999)). Studies of aborted sudden deaths have noted that a subset of patients (those without myocardial infarction) have high recurrence rates (Schaffer and Cobb, 1975) i.e. avoidance of sudden unexpected cardiac deaths does not necessarily lead to substantial gains in life expectancy.

79. Thus, if the distribution of the deaths brought forward by air pollution does indeed roughly follow the baseline distribution of types of cardiac deaths, then the proportion of cardiovascular deaths brought forward which are sudden cardiac arrests without previously known underlying problems may not be trivial. Even so, the numbers are likely to be outweighed by other types of deaths brought forward i.e. cardiovascular deaths brought forward in those already having clinically apparent heart disease plus respiratory deaths brought forward. Scaling the proportions mentioned in paragraph

78 (about 15 to 25% of cardiovascular deaths are sudden cardiac deaths in those without previous history of heart disease), leads to an estimate of 10% to 15% of all deaths brought forward by air pollution (see Box A2.4 at the end of this annex). Further, avoiding deaths brought forward which would have been sudden cardiac deaths does not automatically mean gains in life expectancy in good health.

80. In summary, there are many uncertainties in the evidence for the degree of life expectancy and the state of health of those whose deaths are brought forward by air pollution. However, some general conclusions can be made:

a) Not all the deaths brought forward involve losses of life expectancy of only a few days. There is evidence that many of them involve losses of life expectancy of several weeks to months. Losses of life expectancy of several months or even years in rare cases have not been ruled out.

b) The majority of deaths brought forward are likely to occur in those who are already in poor health but it is possible that a non-trivial proportion of cardiovascular deaths brought forward may occur in people with previously unrecognised heart disease. Deferring deaths brought forward in this group may, in theory, in some cases, lead to gains in 'apparently healthy' life expectancy.

81. It is worth emphasising at this point that the estimate of losses of life expectancy relate only to the group of people whose deaths are brought forward by air pollution. This is in contrast to estimates of losses of life expectancy from long term exposure to air pollution, where the results are averaged across the whole population including those who are unaffected.

82. For particles, there is evidence that long term exposure is associated with losses of life expectancy (Department of Health, 2001a); in fact, this is now widely recognised as the single most important impact of air pollution on health. This is discussed later but is flagged up here to note that the possibility of double counting between losses of life expectancy from short term exposure and from long term exposure may need consideration (see paragraph 101).

83. This may also mean that the assumptions made about losses of life expectancy and state of health for deaths brought forward may be less crucial for particles as the losses of life expectancy from long term exposure may dominate the benefits. This is not so clearly the case for the gaseous pollutants although long term exposure to sulphur dioxide may also be associated with losses of life expectancy (Health Effects Institute 2000; Pope et al 2002; Hedley et al 2002). (COMEAP has not previously been asked to give an opinion on whether these associations are due to sulphur dioxide itself or to other pollutants correlated with sulphur dioxide).

84. For short term exposure, it is much easier to quantify the numbers of death brought forward than to estimate the losses of life expectancy involved. The design of the studies means that it will always be difficult, if not impossible, to derive direct information on losses of life expectancy. It is only possible to estimate these losses indirectly, by making credible assumptions that are based on evidence. In the long term, assumptions about plausible losses of life expectancy may be more firmly supported if the mechanisms of action of the pollutants are better understood. Because it is numbers of deaths brought forward that are quantified, it might at first be thought that deriving willingness to pay to avoid deaths rather than loss of life expectancy might be most appropriate; in fact this is also complicated. This is because air pollution may make only a minor contribution to the occurrence of the death, the underlying disease being the main cause. Using life years allows an appropriate proportion of the reduced life expectancy to be attributed to air pollution, the greater part to the underlying disease, the lesser part to air pollution. Also, if the loss of life expectancy is small and the underlying health state poor, is this death equivalent in monetary valuation terms to a road accident death? (Although some road accident victims may have incipient heart disease by chance, road accidents do not especially affect those seriously ill with lung or heart disease). It is not, in fact, possible to save lives, only to defer deaths. Therefore, the ideal measure to consider is changes in life expectancy rather than changes in numbers of deaths.

A2.5.2 Proposed approach for valuing acute effects

85. According to the available evidence on acute effects given above the proposed approach would be to value changes in life expectancy rather than numbers of deaths, although as explained above, there are uncertainties involved in making assumptions about the loss of life for each death brought forward. Valuing changes in life expectancy implies using a VOLY instead of a VOSL for valuation. Compared to the VOSL literature however, there are only a few studies that generate VOLYs, and some of these, such as the Markandya et al (2004) study, do not generate direct estimates of VOLYs, but instead derive them from VOSLs. Hence, there is some scepticism on whether current evidence on the direct valuation of VOLYs is any better than the use of algorithms to convert VOSLs into VOLYs (as used in the NewExt work). More evidence in this area is needed.

86. Nevertheless, there are also uncertainties in using VOSLs to value deaths brought forward. For example, the Defra study could be used to value deaths bought forward, but in doing this, assumptions are made about the loss of life expectancy involved in order to convert to a VOSL. The Markandya et al (2004) study derived VOSLs directly but the study did not explain the deaths brought forward context so might be inappropriate for deaths brought forward by a small amount in people in poor health. Alternatively, the road accident VOSL could be used but EAHEAP (Department of Health, 1999) thought this was inappropriate as the nature of the deaths differs. So there are just as many uncertainties in using a VOSL as there are in making assumptions about the loss of life expectancy. Hence, the proposed approach is to value life years saved using VOLYs.

87. In order to convert the number of deaths brought forward into changes in life expectancy, the COMEAP estimate of an average of a 2 to 6 month loss of life expectancy per death brought forward from the 2001 COMEAP report is recommended as the best estimate to use. However, as noted in paragraph 73, there is still uncertainty regarding estimates of loss in life expectancy due to short term exposure to air pollution, and the proposed range is mainly inferred from the data rather than being based on direct evidence.

88. As discussed in paragraphs 75-79, there are still uncertainties regarding the quality of the losses of life expectancy due to the short term effects of air pollution. The evidence however suggests that a reasonable approach would be to use the valuation of a loss of life expectancy in poor health as the central position with sensitivity analyses assuming that 10% or 15% of the deaths brought forward involve a loss of life expectancy in apparently good health. These sensitivity analyses also have some level of uncertainty. This includes (i) the assumption that particles affect all types of heart disease equally, (ii) the English data used to derive the proportion of 10% was based only on adults under 65, and (iii) only some patients who experience sudden cardiac death would have had substantial gains in life expectancy in apparently good health if the death had been avoided.

89. Furthermore, another source of uncertainty is the amount of loss of life expectancy in 'good health', i.e. due to cardiovascular disease. Sub-divisions of cardiovascular outcomes and mechanisms of action have been studied more for particles than for other pollutants. In addition, although ozone is associated with cardiovascular mortality, it is not associated with cardiovascular admissions (Department of Health, 2006a; 2006c). While it is not impossible to think of mechanisms by which one might be affected without the other, it does lessen confidence in the causality of the association between ozone and cardiovascular mortality. Thus the levels of uncertainty in the assumptions about losses of life expectancy in apparently good health vary for different pollutants.

90. The two valuation studies used different approaches for valuing acute effects. The Chilton et al (2004) study directly estimated WTP to avoid air pollution induced fatalities and some morbidity effects. The questionnaire used in the survey also allowed the elicitation of values for avoiding acute and chronic health effects separately. As explained in section A2.4.2.1, in the context of acute effects the Chilton et al (2004) study asked respondents to value increases in life expectancy in poor health. The exact description of this Good P is summarised in Box A2.1 below.

Box A2.1: Explanation of Good P increases in life expectancy in poor health

X MONTHS MORE LIFE IN POOR HEALTH WHEN ELDERLY. This would be most likelyto benefit elderly people with heart or lung disease. By reducing the number of bad air days, such people could expect to live about X months longer, although this extra time would be spent in their existing poor state of health.

91. Eliciting a WTP for Good P means respondents are taking into account the futurity of the benefit, and are also making some adjustments for the lower quality of life. A VOLY generated from the valuation of Good P would therefore seem to be applicable to the proposals on how to quantify the health effects.

92. However, the WTP for Good P is not without associated uncertainties. The lack of sensitivity to scope in the Chilton et al (2004) study implies that respondents may not have been expressing their true valuation of the good but simply thinking of their disposable income. Furthermore, a number of health experts and economists at the Defra workshop were not convinced that respondents who have not experienced the relevant health effect can accurately value it, and hence, may tend to underestimate it. Therefore, the VOLY associated with poor health could be considered a conservative valuation.

93. The Markandya et al (2004) study considered the health effects of respondents by recording their health status and asking them whether they thought of their health status when answering questions. This study analysed the effects of health on WTP by using three dummy variables: one takes account of whether the respondent has suffered from any chronic cardiovascular or respiratory illnesses; the second takes account of whether the respondent has been hospitalised or has gone to the emergency room in the last five years for a heart or lung problem; and the third dummy accounts for whether the respondent has or has had cancer. The analysis showed that for, the UK sample, having a chronic heart or lung condition has a positive and significant influence on WTP. The other two health dummies were not statistically significant. Unlike the Chilton et al study therefore, the Markandya et al study provides some limited evidence that WTP is affected by illness but that WTP increases instead of decreases. As this evidence is limited though no strong conclusions can be inferred about the relationship between health and WTP from the Markandya et al study.

94. When considering how appropriate the results from the Markandya et al (2004) study are for valuing increases in life expectancy in poor health it is necessary to remember that this study did not directly value changes in life expectancy, but valued changes in the risk of mortality. Uncertainties arise with this approach as it has been argued that respondents may not have been correctly translating mortality risks to life expectancy changes. Previous work (discussed by Brigitte Dessaigues at the workshop) has suggested that respondents tend to assume that the life expectancy increases associated with the levels of risks reductions they are being asked to value are larger than the actual reductions. It is also unclear whether the respondents would have given different answers if they had known the deaths were likely to occur when they were already ill.

95. Furthermore, it is also not clear which risk reduction scenario in the Markandya et al (2004) study is relevant for acute effects. Acute effects associated with air pollution affect the elderly within a population (as discussed above). Hence, when asked about valuing reductions in mortality risks it is perhaps the future mortality risk that is most relevant to acute effects (assuming average age of respondents is lower than 60). If this was the case the poor health VOLY for the Chilton et al (2004) study (£14,000) is consistent with the VOLY from the Markandya et al (2004) future risk reduction (£17,000).

96. Although both studies consider the health status of respondents, the Chilton et al (2004) study specifically asks respondents to consider extensions in life expectancy in poor and normal health. Hence these values would appear more relevant for valuing acute effects, as they value changes in life expectancy (life years saved) and take explicit account of the fact that the increased life expectancy occurs in poor health. The proposed value of a VOLY applied to acute effects would therefore be £14,280 (2002 prices), as per the Chilton et al poor health VOLY. However, uncertainty within the literature remains about whether people could value future benefits and poor health accurately, and further work could usefully be carried out in this area.

97. Paragraph 88 above suggests that although the central position should be that life years saved for acute effects are predominantly in poor health, sensitivity analysis can be carried out to account for the smaller number of life years saved that can be considered as being in normal health. In this case the valuation of increased life expectancy in normal health is the relevant valuation. The valuation for normal health in the Chilton et al (2004) study generates a VOLY of £27,630 (2002 prices), based on the 1-month sample, which is consistent with a VOLY derived from the DfT Value of a Prevented Fatality.[14] Further discussion on why the Chilton et al (2004) VOLY for normal health is used can be found in section A2.6.2.

A2.6 Valuing chronic health effects

A2.6.1 Health evidence on the chronic effects

98. The evidence for an effect of long term exposure to particles on life expectancy comes from a different design of study (a cohort study). This type of study takes a group of people, takes advantage of the different measures of long term exposure for different individuals or sub-groups of people and then records when people die over the years that follow. In the case of the air pollution studies, people from more polluted cities and less polluted cities were compared and it was found that, having taken account of age, race, gender, smoking habits and other risk factors, the people from the more polluted cities died earlier than the people from the less polluted cities.

99. There are only a handful of studies of this type. There are two main studies from the United States (Dockery et al 1993; Pope et al 1995; 2002). Similar results have also been shown in a study in Europe, although this examined exposure close to roads (Hoek et al, 2002). These studies do not give direct information on the mechanism responsible for the loss of life expectancy. However, there are a few pointers. The original US studies did not study cardiovascular mortality and respiratory mortality separately but an extension of the analysis of the US cohort studies (Health Effects Institute, 2000) did. This found that the loss of life expectancy was mainly due to cardiovascular rather than respiratory disease. Treating this simplistically, this could either be because people are dying earlier because they developed cardiovascular disease earlier, or because their cardiovascular disease became more severe faster. In the former case, there could be a loss of life expectancy in good health as a result of developing heart disease earlier. In the latter case, the loss of life expectancy would occur in poor health. Of course, in practice, both a gain of life expectancy in good health and a gain of life

[14] The Department for Transport VPF of £1.2 million has been extensively peer reviewed and is used widely within government. If it is assumed that this VPF is for an average of 40 years, then the derived VOLY= £1.2 million/40 = approx £31,000.

expectancy in poor health could occur. No statistically significant increased risk was found in people with pre-existing heart or lung disease as would be expected if the effect predominantly occurred by increasing the progression of disease. So it is perhaps reasonable to consider that reducing air pollution could result in gains in life years in good health. It cannot be said though that this view is strongly established, as the mechanisms involved have not been thoroughly examined.

100. In calculating the loss of life years for cost-benefit analysis, the change in hazard rate suggested by the cohort studies is applied to standard lifetables. Apart from only being applied to the over 30s (the study by Pope et al (1995) only studied the over 30s), the hazard rates are applied to the usual baseline with the usual distribution of age at death. The method does not select particular susceptible subgroups. Thus, it could be said that the method is applied to a typical population with the usual distribution of quality of life. One could therefore assume that there is a loss or gain in life years in 'typical health' rather than particularly poor health. [The method is capable of applying to particular susceptible subgroups (Miller and Armstrong, 2001) but, as it is unknown whether the long term effects of particles apply to particular susceptible subgroups or not, this has not been used in quantification.]

101. It is known that some of the loss of life years could be in poor health as the deaths brought forward as a result of short term exposure involve a loss of life years in poor health, but it is likely that this proportion is very small. COMEAP estimated, making several assumptions, that the life years gained from a drop of 1µg.m^{-3} in $PM_{2.5}$ from the short term effects are at least ten fold lower than the lowest estimates from the long term effects (Department of Health, 2001a). This presumes the results do not overlap but it is possible that there is some overlap. For example, if losses of life expectancy are more than a month for the effects of short term exposure, these effects could, in theory, be detected by the cohort studies (which checked time to death every month). However, the contribution of these effects as a proportion of total life expectancy changes may be too small to be distinguished from 'noise' in the data. This has been considered in detail in an Institute of Occupational Medicine report commissioned by the Department of Health (Miller and Armstrong 2001). This also concluded that the impact of the short term effects on changes in life years was likely to be small. The report concluded that the cohort studies identify deaths advanced by a long time, whether caused by immediate or delayed effects of air pollution, and that total life years gained could thus be estimated from cohort studies alone. Of course, this point only applies to those pollutants showing effects in the cohort studies ($PM_{2.5}$ and perhaps sulphur dioxide). (Long term exposure to PM_{10} was less strongly related to mortality than long term exposure to $PM_{2.5}$ but, of course, $PM_{2.5}$ makes up a substantial portion of PM_{10}).

102. The lifetable calculations give results in terms of total loss of life years across the population but are not entirely clear what the range in the loss of life years per person might be. The 2001 COMEAP report on long term effects of particles estimated that a reduction of 1µg.m^{-3} in $PM_{2.5}$ would lead to gain of 0.2 to 0.4 million life years for the population alive today, followed for a lifetime. If these were distributed evenly across the population, then this would equate to 1 to 3 days per person, but, if fewer people were affected the loss of life expectancy could be a few months or even a few years

per person.[15] The answer to this is unknown. This might not matter too much for valuation purposes if the relationship between life years lost and willingness to pay is linear but this may not be the case. This may need to be addressed by further research in the longer term.

103. A further development since the 2001 COMEAP report, is the publication of a longer follow up of the ACS cohort study (Pope et al, 2002). This confirmed earlier findings but also found a statistically significant increased risk for lung cancer associated with $PM_{2.5}$ for the first time. Increased but non-significant risks had been found in the earlier publication of results from the ACS study (Pope et al, 1995) and the Six Cities study (Dockery et al, 1993). COMEAP will consider this more recent study when they update the 1998 Quantification report. However, it is worth raising it now as an effect on lung cancer could affect valuation – both as a result of the 'dread' factor and also the implications for loss of life expectancy per person. (If air pollution is the sole cause of lung cancer in some, probably very small, number of cases, then there is the possibility of a substantial loss of life expectancy for a particular individual. On the other hand, on a population basis, the loss of life expectancy is likely to be less than for heart disease as lung cancer is less common and occurs at older ages).

A2.6.2 Proposed approach for valuing chronic effects

104. Section A2.6.1 discusses the health evidence on the chronic effects of air pollution. It is stressed that the mechanism of the effect of long term exposure to particles has not been thoroughly examined, and that current information is based on a limited number of studies. However, based on the existing information it is reasonable to assume that most life years lost due to the long term effects of air pollution would be in good health. The value attached to the loss of life expectancy due to chronic effects should be based on respondent's assuming the losses in life expectancy occur in normal health.

105. The use of cohort studies also indicates that chronic effects should be measured in terms of life years lost instead of deaths brought forward. Consequently, a value for changes in life years, i.e. a VOLY, is the relevant valuation to apply to chronic effects.

106. Currently, the only UK study that directly generates VOLYs is Chilton et al (2004). In Markandya et al (2004), VOLYs are derived from VOSLs using algorithms and there is a ongoing debate on whether derived VOLYs are better or worse than ones that are directly elicited in questionnaires. The robustness of derived VOLYs depends largely on the algorithms used, on which there is not much current evidence. The VOLYs for normal health in the two studies we have focused on are fairly similar (£41,975 in the Markandya et al relative to £27,630 in the Chilton et al). As the Chilton et al VOLY is directly valued, and the description of the good used in this study accurately describes the health effects associated with long term exposure to air pollution, it is recommended that the value from this study (£27,630 – 2002 prices) is used for the valuation of chronic effects. However, given that the chronic effects of particles are

[15] It is likely that some people are more susceptible than others to air pollution but relatively little is known about the factors affecting susceptibility. The cohort studies found greater effects in those with less than high school education. For the short term effects, there are some suggestions that the elderly are more at risk, although whether this is due to the fact that heart and lung disease are more common in the elderly or due to age per se is unknown. It has been suggested that diabetics are more at risk although this may be indirect as diabetics are more susceptible to heart disease. There are also studies of genetic risk factors for responses to ozone. More research is needed to understand the most important susceptibility factors.

now widely recognised as the single most important impact of air pollution on health, and the uncertainties regarding the valuation of health effects, it is proposed that the 95% confidence intervals around this figure, £20,690 – £34,440, are used as a sensitivity analysis. This sensitivity however does not account for all the associated uncertainties.

A2.7 Valuing morbidity effects

A2.7.1 Quantification of morbidity effects

107. This paper also aims to recommend, where possible, ways of valuing morbidity endpoints associated with air pollution. Air pollution may bring death forward and shorten people's life expectancy but it is also likely to cause many more to be ill. Morbidity impacts can be of varying severity, such as that which causes pain and severely limits people's ability to perform normal daily activities and might require hospitalisation, through to less severe morbidity which may have unpleasant symptoms but may only limit activities to a small extent. As the morbidity endpoints constitute a smaller proportion of the health impacts compared with mortality, the valuation of morbidity endpoints requires less discussion and scrutiny. This section therefore will not cover the morbidity endpoints in as much detail as the mortality valuation.

108. Before moving onto the valuation of morbidity effects associated with air pollution, it is necessary to set out which morbidity endpoints we propose to value. Previously the IGCB has quantified respiratory hospital admissions caused by exposure to NO_2, SO_2 and PM_{10} and cardiovascular hospital admissions caused by exposure to PM_{10}, which follows the advice set out in COMEAP (Department of Health, 1998; 2001b). It is proposed that the same endpoints are quantified and valued as reliable evidence is still lacking on morbidity, other than hospital admissions.[16] The following section provides more information on how the two types of hospital admissions are quantified.

109. Time series studies give information on the number of hospital admissions each day and correlate this with the level of air pollution each day. They do not give any information on whether the hospital admissions are additional (i.e. would not have occurred at all if pollution had not increased) or brought forward (declining health status was accelerated by increased pollution leading to a hospital admission at an earlier time than if pollution had not increased).

110. It is usual to quantify hospital admissions for all respiratory admissions. This avoids difficulties of misclassification between one type of respiratory disease and another. It is important to be aware, however, that this represents a mixture of admissions of different types including asthma admissions (which are more common in younger age groups) and chronic obstructive pulmonary disease (COPD) admissions (which occur mainly in the elderly).

[16] To note that the proposed cost-benefit methodology for the Clean Air for Europe (CAFE) Programme will include quantification and valuation of a number of other morbidity effects such as restricted activity days, asthma attacks etc. However, the quantification methodology for these additional effects proposed for CAFE is primarily based on evidence from the US. At the time, COMEAP had not reviewed the latest evidence and considered its applicability to the UK.

111. There are also many time series studies that examine admissions for all cardiovascular diseases (ICD code 390-459). It should be noted that this includes diseases of the heart and of the circulation (e.g. stroke). There are some indications that air pollution is less likely to affect stroke admissions than cardiac (heart disease) admissions. This is of importance for valuation studies because the length of stay in hospital and the quality of life implications are greater for stroke admissions than for heart disease admissions.

112. There is no direct information on the length of stay in hospital for an admission triggered by air pollution. In fact, it is not possible to identify which these admissions are – statistically there are more hospital admissions on high pollution days but the 'extra' admissions are not classified any differently from the 'baseline' admissions. So, in the absence of information to the contrary, it can be assumed that the distribution of length of stay in hospital is similar to the distribution of length of stay for a particular type of hospital admission in general.

113. Table A2.10 below gives information on the length of stay in general for respiratory hospital admissions and for hospital admissions for 'ischaemic heart disease and other heart disease' (note this is only a subset of all cardiac or all cardiovascular admissions).

Table A2.10: Spells in NHS hospitals by patients admitted as emergency admissions with a main diagnosis on discharge of diseases of the respiratory system and of heart disease and NHS costs (1996/97 prices).

NHS England 1994/95	< 65 years	65+ years	All ages
Primary diagnosis ICD(9): 450-519:diseases of the respiratory system			
Average length of stay (days)	3.9	13.6	7.7
Cost per spell: £[17]	705 (838)	2,460 (2,920)	1,390 (1,650)
Primary diagnosis ICD(9): 410-429: ischaemic & heart disease			
Average length of stay (days)	6.4	10.6	9.2
Cost per spell: £[18]	1,030 (1,220)	1,710 (2,030)	1,485 (1,765)
Source: The length of stay in hospital is taken from the NHS Hospital Episode Statistics 1994/95 – as reported in EAHEAP (Department of Health, 1999). Data on the cost per day of a hospital admission is derived from the Chartered Institute for Public Finance and Accountancy (CIPFA) Health database.			

114. The severity of disease involved is very variable for both respiratory and cardiovascular admissions. It can vary from being admitted overnight for observation through to life-threatening situations. There is no information on whether air pollution affects one level of severity of admission more than another.

[17] Numbers in brackets are the values converted to 2004 prices assuming an inflation rate of 2.5%.

[18] Numbers in brackets are the values converted to 2004 prices assuming an inflation rate of 2.5%.

A2.7.2 Valuation of morbidity

115. In order to value morbidity it is necessary to identify the components that generate the total change in welfare derived from the occurrence of morbidity. These components are:

- Resource costs – medical costs incurred by the health service (such as time spent by GPs, the cost of drugs, spells in hospital) and private costs of dealing with illness (such as travelling to see a doctor);
- Opportunity costs – the cost in terms of lost productivity and the opportunity cost of leisure including non-paid work; and
- Disutility – the wider disutility of ill-health both to the individual and his/her family and friends; sometimes referred to as 'pain, grief and suffering'.

116. Trying to disentangle these three components can be difficult; for example, it is possible that when stating their WTP to avoid a hospital admission, respondents are also reflecting elements of the resource and opportunity costs of that admission in their answers. It is believed however, that as the bulk of financial costs are borne by others and the private costs to an individual are likely to be small, WTP to avoid the disutility of ill-health is unlikely to incorporate any of the other costs. Hence, it is suggested that to derive the total cost of a respiratory admission, costs for the three components listed above are added. The valuation of these three components will be discussed in turn in the following sub-sections.

A2.7.2.1 Resource costs

117. Resource costs in terms of the costs to the NHS are available for respiratory hospital admissions and cardiovascular admissions in the EAHEAP (Department of Health, 1999) report. These resource costs are illustrated in Table A2.10 above and are based on a cost per day figure of £181 for a respiratory hospital admission (based on the average cost of an inpatient day in a thoracic ward) and £161 for cardiovascular admissions (based on the average cost for an inpatient day in a medical ward). Pearce et al (1998) also report health service costs per in-patient day for a number of EU countries, including the UK. The UK figure is £329 (2000 prices) and includes both capital and operating costs. When compared to the values reported in the EAHEAP report (after the necessary currency conversions are made) these two values are very similar. However, as the data presented in the EAHEAP report is differentiated by the type of hospital admission, that data will be used in the remainder of this paper.

A2.7.2.2 Opportunity costs

118. Incidences of morbidity could result in absenteeism and a consequent loss of work output. Whether this cost is borne by the employee or the employer depends on how labour markets function. Pearce et al (1998) present benchmark estimates of daily loses due to absenteeism based upon reported wage rates in several EU countries. For the UK, the per diem production loses due to absenteeism cost €58 (2000 prices).

119. Another source of information on the cost of absenteeism is a survey carried out by the Confederation of British Industry (1998) and reported in the methodology report (Volume II) for the Clean Air for Europe (CAFE) Programme (Hurley et al, 2005). In the CBI survey respondents were asked to quantify the direct costs of absence, which was based on the salary costs of absent individuals, replacement costs and lost service or production time. The authors of the CBI report used the median estimate of €85 (1998 prices) as the better indicator of average costs as the mean estimates were skewed. AEA Technology (Hurley et al, 2005) also reports the indirect cost (e.g. costs associated with lower consumer satisfaction and lower quality products) per day of absence per employee as €253. However, the value of indirect costs was based on a very small sample of employers, hence AEA Technology use the direct cost estimate of €85 as their central value for the cost of absenteeism and use the indirect costs as sensitivity. In pounds sterling and 2004 prices this figure becomes £62.

120. EAHEAP note that the loss in work output due to air pollution induced morbidity will be negligible as the elderly and seriously ill will be most affected, of which the vast majority are expected to be above retirement age anyway. EAHEAP suggest that it is possible that some of those admitted to hospital could be young and less seriously ill but there was insufficient evidence to define the number of patients in this category. EAHEAP speculated that it was probably small. Given the conclusions in the EAHEAP report, one potential way forward would be to use the methodology AEA Technology have adopted for CAFE as a sensitivity analysis and assume that the opportunity costs due to lost output are negligible as the central estimate, thus reflecting an upper and lower bound for the loss of output.

A2.7.2.3 Disutility

121. Much of the work undertaken to value the disutility of morbidity effects has used revealed preference techniques and in particular contingent valuation. In the previous sections of this paper, evidence on valuing mortality effects was drawn primarily from the Chilton et al and Markandya et al studies. However, the Markandya et al study did not value morbidity endpoints. The literature review (Eftec 2004) describes four studies that estimate values for different morbidity effects. The Maddison et al study will not be looked at in detail here, as although it examines a variety of morbidity effects it does not cover hospital admissions. The ExternE (1995; 1999) values discussed relied heavily on the available literature which at the time was a small sample of US studies. The ExternE work has now been updated to incorporate the Pearce et al (1998) study. Hence the main studies considered here for valuing hospital admissions are Chilton et al and Pearce et al (1998). The Pearce et al (1998) study is also reported in Pearce (2000) and Ready et al (2004). These studies estimate values for a number of morbidity endpoints. However, since only hospital admissions can be quantified with reasonable certainty (Department of Health, 1998; 2001a), this annex will focus on the valuation of these.

122. Nevertheless, the approach used by Maddison (2000) is worth noting as EAHEAP suggested, at the time, that it would be the most 'fruitful approach to improving the existing literature' (Department of Health, 1999). Maddison integrated 'quality of well being' (QWB) indexes with WTP estimates and derives a meta-equation to

describe the general relationship between WTP, QWB scores and days.[19] While there are few estimates to compare, the Maddison results do not seem unreasonable when compared with the estimates derived from original contingent valuation studies. This method could usefully be examined further as if it proved reliable it should be possible to interpolate values for health conditions which have not been directly assessed, but which can be given QWB scores.

123. The methodology used in the Chilton et al (2004) study is summarised in section A2.4.2.1 of this annex. Box A2.2 below (also illustrated in Table A2.6) describes the respiratory hospital admission benefit that respondents were asked to value in the Chilton et al study. This benefit will be referred to as Good H. It should also be noted that Good H was one of four goods respondents had to allocate a proportion of their total WTP to avoid.

Box A2.2: Description of the Respiratory Hospital Admission Benefit in the Chilton et al (2004) study

"AVOIDING AN ADMISSION TO HOSPITAL WITH BREATHING DIFFICULTIES. This would be most likely to benefit people in their 70's and 80's who have some kind of lung disease, or younger people with asthma or other chest conditions. By reducing the number of bad air days, such people would be less likely to develop attacks of breathing difficulties which require admission to hospital."

124. The resulting WTP estimates are presented in Table A2.11 below. The survey asked respondents how much their household would be willing to pay per year, in the form of higher prices, to avoid an admission to hospital with breathing difficulties. The answer to this question is listed in the third row of Table A2.11. The authors then translated the household WTP into a WTP per person,[20] and this is indicated in the second row of Table A2.11. The total WTP per person and per household is calculated by multiplying the annual WTP figures by the average life expectancy (78 years). The total values per person and per household can be seen in rows 4 and 5 of Table A2.11 respectively.

125. Paragraph 45 explained that the authors also investigated whether respondents were valuing the losses of life expectancy in poor health as a certainty or whether they were considering the likelihood of them experiencing that poor health state. The same issue is also relevant to the morbidity effects as respondents may have been considering the likelihood of experiencing the hospital admission when valuing it, instead of valuing the certainty of it occurring. To account for this uncertainty in respondent's responses, the authors calculate a likelihood-adjusted value for a respiratory hospital admission, which is indicated in the 4th and 5th row.

[19] Days = variable describing the duration of the morbidity effect.

[20] The conversion of household WTP to per person WTP was carried out by: (household mean x total number of households)/total number of individuals.

Table A2.11: Chilton et al (2004) study values for avoiding an admission to hospital with breathing difficulties – Good H (2002 prices)

	Full Sample Results[21]
Annual WTP (per person)	£16.77 (17.62)
Annual WTP (per household)	£35.65 (37.45)
Value of avoiding a respiratory hospital admission (per person) **Likelihood adjusted**	£1,310 (1,376) £3,340 (3,509)
Value of avoiding a respiratory hospital admission (per household) **Likelihood adjusted**	£2,780 (2,921) £7,110 (7,470)

126. The Pearce et al (1998) study is a meta-analysis of morbidity valuation estimates in the European Union (including Norway). This study carried out contingent valuation studies in Portugal, the Netherlands, Norway, Spain and the UK for health effects that were thought to be associated with air pollution. This study also tried to test the effects of context and the validity of benefits transfer. The central estimates are reported and discussed here.

127. In terms of hospital admissions, the precise good that was being valued in this study is illustrated in Box A2.3 below.

Box A2.3: Description of the respiratory hospital admission benefit in the Pearce et al (1998) study

Hospital

Hospital Admission for COPD, pneumonia, respiratory disease and asthma

Admission to hospital for treatment of respiratory distress. Symptoms include persistent phlegmy cough, with occasional coughing fits, gasping for breath, fever, headache and tiredness. Patient stays in the hospital receiving treatment for three days, followed by 5 days at home in bed.

128. The central estimates from the Pearce et al (1998) study are listed in Table A2.12 below. The second column reports the pooled result from the five different countries and the third column reports the UK estimate. The number in brackets is the original 1998 estimate updated at 2% inflation rate and converted to pounds sterling as reported in Ready et al (2004).

[21] Numbers in brackets are the values converted to 2004 prices assuming an inflation rate of 2.5%.

Table A2.12: Pearce et al (1999) study values for avoiding an admission to hospital – Euros (1999 prices)

	Pooled	UK
Hospital	€490 (€554)	€262
In 2004 UK sterling (£) prices[22]	£382	£204

129. Comparing the Chilton et al estimates of the value of a respiratory hospital admission with those reported in Pearce et al, there appears to be substantial disparity between the two values. Although the description of the symptoms associated with the respiratory hospital admissions is similar in both studies, the length of stay in hospital is different. The Pearce et al study refers to the admissions lasting three days 'followed by 5 days home in bed'. On the other hand, the Chilton et al study refers to the possibility of staying in hospital from a day or two, up to a couple of weeks'. The longer stay in hospital in the Chilton et al study does partly explain the higher values, as when the average value of avoiding one day in hospital is examined (the Pearce et al study yields a figure of £70[23] and the Chilton et al study yields a figure of £530[24] (2004 prices)) the disparity between the two values becomes much smaller. However, the value of an average stay in hospital is of most use in appraisal as the epidemiological studies yield the total number of hospital admissions, rather than the total numbers of days admitted to hospital.

130. The NHS evidence illustrated in Table A2.10 indicates that the average length of stay for a respiratory hospital admission is 7.7 days and can be as much as 14 days. The recommendation made by the authors of the Chilton et al study to use a range based on the lower value of £1,380 and the higher value of £7,470 (2004 prices) does not seem unreasonable, as the length of stay valued in this study is consistent with the medical evidence. There are no strong reasons however to disregard the Pearce (1998) figure (and it is also being used in appraisals carried out by the EU). Hence, the proposed approach in this paper would be to use the Pearce et al (1998) value of £204 (2004 prices) as a lower bound and the Chilton et al value of £7,470 (2004 prices) as an upper bound.

A2.7.3 Cardiovascular admissions

131. The valuation literature has focussed on estimating the WTP associated with respiratory hospital admissions. To our knowledge, there is no empirical evidence to date on valuing the WTP of avoiding cardiovascular admissions. It is unknown whether the WTP to avoid a cardiovascular hospital admission would be significantly different to that of a respiratory hospital admission. In terms of severity of disease both respiratory and cardiovascular admissions cover a wide range of severity and involve a similar length of stay in hospital and it is therefore not possible to conclude that one type of disease is necessarily worse than the other. However, it is possible that valuation would be different because an admission with a suspected heart attack could be a more unexpected development to the individual. Some respiratory admissions are very

[22] Numbers in this row are the original values converted to 2004 prices assuming an inflation rate of 2.5%. Where euros have been converted to British pounds a conversion rate of 1 euro: 1.45 pounds was used.

[23] £70 = total value/number of days in hospital used to description of health effect to respondents = £204/3

[24] £510 = total value/number of days in hospital used to description of health effect to respondents = £7,470/14

serious but are more likely to occur in people whose health has gradually deteriorated over time. Going from 'apparently healthy' to having a heart attack suddenly presents someone with the idea that they have a potentially life threatening disease. One might argue therefore that the 'dread factor' associated with cardiovascular admissions is higher and that may lead to higher WTP to avoid these admissions relative to respiratory hospital admissions.

132. However, due to the lack of empirical evidence on WTP to avoid cardiovascular admissions however, it will be assumed that the WTP is equal to that of avoiding a respiratory hospital admission and will therefore range from £204 to £7,470 (2004 prices)

A2.7.4 Recommendations

133. Following the discussion in section A2.7 the following recommendations can be made:

Respiratory Hospital Admissions

Central Estimates (2004 prices):

Total Value of a Respiratory Hospital Admission =

Resource cost (£1,650) +

Opportunity cost (0) +

Disutility (£204 – £7,470) = **£1,854 – £9,120**

Sensitivity analysis (2004 prices): The opportunity costs, reflected in the costs of absenteeism for 8 days worth £496 could also be added to the upper range of the values which would change the range of the total cost of a respiratory hospital admission to: **£2,350– £9,616.**

Cardiovascular Hospital Admissions

Central Estimate (2004 prices):

Total Value of a Cardiovascular Hospital Admission = Resource cost (£1,765) +

Opportunity cost (0) +

Disutility (£204 – £7,470) = **£1,970 – £9,235**

Sensitivity analysis (2004 prices): The opportunity costs, reflected in the costs of absenteeism for 9 days worth £558 could also be added to the upper range of the values which would change the range of the total cost of a cardiovascular hospital admission to: **£1,970– £9,793.**

A2.8 Summary of recommendations

134. Table A2.13 below summarises the recommendations made above in this paper. The sensitivities suggested below do not account for all the uncertainties associated with the application of these values. There are still areas of uncertainty that have not yet been resolved due to a lack of conclusive evidence on aspects of both the valuation and the health evidence that underpin some of these recommendations. These recommendations will therefore be reviewed as necessary in light of any further, relevant research.

135. Equally, the health effects below present a subset of all the possible health effects avoided when air pollution is reduced. The reason for this is that there are too many uncertainties involved with quantifying the other impacts on health. The health effects presented below are those that have been recommended by COMEAP for quantification.

Table A2.13: Summary of recommendations

Health Effect	Form of measurement to which the valuations will apply	Valuation – (2004 prices)	
		Central Value	*Sensitivity*
Acute Mortality	**Number of years of life lost due to air pollution (life years)** – assuming 2-6 months loss of life expectancy for every death brought forward. Life-expectancy losses assumed to be in poor health.	£15,000	10% and 15% of life years valued at £29,000 instead of £15,000 (to account for avoidance of sudden cardiac deaths in those in apparently good health)
Chronic Mortality	**Number of years of life lost due to air pollution (life years)** – Life-expectancy losses assumed to be in normal health.	£29,000	£21,700 – £36,200 (sensitivity around the 95% confidence intervals)
Respiratory Hospital Admissions	**Case of a hospital admission** – of average duration 8 days.	£1,900 – £9,100	£1,900– £9,600
Cardiovascular Hospital Admissions	**Case of a hospital admission** – of average duration 9 days.	£2,000 – £9,200	£2,000 – £9,800

136. It is important to note where these values can be applied. The monetary values themselves are not restricted as to where they apply, but the underlying quantification of health benefits only generally apply to broad changes in air pollution concentrations. This is because the health studies are based on changes in concentrations at background monitoring sites. The concentrations at background monitoring sites act as a surrogate for the general distribution of personal exposures. It is unlikely that changes to concentrations near to local sources such as industrial sites[25] or roadsides act as surrogates for the general distribution of personal exposures (and any resulting health effects) in quite the same way.

A2.9 Areas where further work is required

137. While gathering evidence and making recommendations on the valuation of health effects it became evident that there are a number of areas on the valuation aspects requiring further research. Some of these are:

a) Deaths brought forward due to air pollution can have different characteristics and hence it could be argued that the various possible characteristics of a death brought forward should be described separately and specific valuations should be asked for in each case. It is difficult to disentangle mortality from morbidity valuation but there might be a range of views about, for example, sudden cardiac death compared with death from COPD following a few years struggling with a poor quality of life. The effect of quality of life on valuations (poor health vs normal health) could also be further examined in this respect. This issue can only be resolved with further investigation.

b) Further work into using algorithms for converting VOSLs into VOLYs is required.

c) Evidence on the quantification and valuation of other morbidity end points.

d) Further investigation of whether it is possible to successfully integrate WTP with different QWB scores, such as the EQ5D score or more specific health status measures.

138. There are also a number of areas requiring further research on the health evidence underlying the quantification approach to health benefits associated with reductions in air pollution. A number of these areas will be addressed in the forthcoming COMEAP report updating the 1998 and 2001 COMEAP reports.

[25] This issue is discussed in a statement from COMEAP on the applicability of time-series coefficients to areas affected by emissions of air pollutants from industrial sources, which is available at http://www.advisorybodies.doh.gov.uk/comeap/statementsreports/areaemissions.htm

Box A2.4: Calculation of sudden cardiac deaths with no previous history of heart disease as a proportion of all deaths brought forward by air pollution

1. The calculation is based on 2003 ONS Mortality Statistics for England and Wales. (http://www.statistics.gov.uk/downloads/theme_health/Dh2_30/DH2No30.pdf)
2. The exposure-response functions are from the WHO Meta-analysis of time-series studies and panel studies of Particulate Matter (PM) and Ozone (O_3), World Health Organisation Regional Office for Europe, 2004 (http://www.who.dk/document/e82792.pdf)
3. The WHO meta-analysis includes exposure response functions for all cause mortality and for respiratory and cardiovascular mortality. The 1998 report from the Committee on the Medical Effects of Air Pollutants (COMEAP) 'Quantification of the Effects of Air Pollution on Health in the United Kingdom' only recommended the use of an exposure-response function for all cause mortality as this avoids problems of misdiagnosis between respiratory and cardiovascular causes. This caveat should be borne in mind – this calculation is intended to provide only a broad idea of the possible proportion of deaths brought forward by air pollution which might be sudden cardiac deaths without a previous history of heart disease.
4. It is assumed that the exposure response functions for PM_{10} are roughly analogous to the exposure-response functions for other pollutants – this is not true in detail but is sufficient to illustrate the calculation and give a broad idea. The proportion could be recalculated using exposure-response functions for other pollutants, if necessary.
5. The calculation is done for a presumed 10µg.m^{-3} increase in PM_{10}. This is a theoretical example to derive the relevant proportions – it is not likely in practice that an annual average increase of 10µg.m^{-3} in PM_{10} would occur. In fact, annual averages are declining.
6. It is assumed that air pollution affects different cardiovascular causes equally. It is unknown whether this is the case.
7. It is estimated that sudden cardiac deaths with no previous history of heart disease make up from 15% to 25% of all cardiovascular deaths. See paragraphs 78-79 of the main paper for references.

   Number of cardiovascular deaths brought forward by air pollution:

   - Total number of cardiovascular deaths in 2003: 205,508
   - Exposure-response functions for cardiovascular mortality: 0.9% per 10µg.m^{-3} PM_{10}
   - Total number of cardiovascular deaths brought forward by 10µg.m^{-3} PM_{10}: 0.9% x 205,508 = 1,850

Box A2.4: Calculation of sudden cardiac deaths with no previous history of heart disease as a proportion of all deaths brought forward by air pollution *(continued)*

Number of sudden cardiac deaths brought forward by air pollution:

a) If 25% of all cardiovascular deaths are sudden cardiac deaths with no previous history of heart disease, and PM_{10} affects all cardiovascular deaths and sudden cardiac deaths equally:

- 25% x 1,850 = 462 sudden cardiac deaths with no previous history of heart disease brought forward by 10µg.m^{-3} PM_{10}

b) If 15% of all cardiovascular deaths are sudden cardiac deaths with no previous history of heart disease, and PM_{10} affects all cardiovascular deaths and sudden cardiac deaths equally:

- 15% x 1,850 = 278 sudden cardiac deaths with no previous history of heart disease brought forward by 10µg.m^{-3} PM_{10}

8. These numbers then need to be compared with total deaths brought forward by air pollution. This can be done in two ways (i) by comparing with the total of the respiratory plus the cardiovascular deaths brought forward or (ii) by comparing with the number of all cause deaths brought forward. These calculations are given below.

Number of respiratory deaths brought forward by air pollution:

- Total respiratory deaths in 2003: 75,138
- Exposure-response functions for respiratory mortality: 1.3% per 10µg.m^{-3} PM_{10}
- Total number of respiratory deaths brought forward by 10µg.m^{-3} PM_{10}: 1.3% x 75,138 = 977

Total number of respiratory plus cardiovascular deaths brought forward:

- Total respiratory plus cardiovascular deaths brought forward by 10µg.m^{-3} PM_{10}: 1850 + 977 = 2,827

Proportion of sudden cardiac deaths brought forward to all cardiovascular plus respiratory deaths brought forward:

a) If 25% of all cardiovascular deaths are sudden cardiac deaths with no previous history of heart disease, and PM_{10} affects all cardiovascular deaths and sudden cardiac deaths equally:

- 462 sudden cardiac deaths brought forward out of 2,827 respiratory plus cardiovascular deaths brought forward (16%)

b) If 15% of all cardiovascular deaths are sudden cardiac deaths with no previous history of heart disease, and PM_{10} affects all cardiovascular deaths and sudden cardiac deaths equally:

- 278 sudden cardiac deaths brought forward out of 2,827 respiratory plus cardiovascular deaths brought forward (10%)

Box A2.4: Calculation of sudden cardiac deaths with no previous history of heart disease as a proportion of all deaths brought forward by air pollution *(continued)*

Number of all cause deaths brought forward by air pollution:

- Total all cause deaths in 2003: 538,254
- Total deaths from external causes in 2003: 16,693
- Total all cause deaths excluding external causes in 2003: 521,561
- Exposure-response functions for all cause mortality: 0.6% per 10μg.m^{-3} PM_{10}
- Total number of all cause deaths brought forward by 10μg.m^{-3} PM_{10}: 0.6% x 521,561 = 3,129

Proportion of sudden cardiac deaths brought forward to all cause deaths brought forward:

a) If 25% of all cardiovascular deaths are sudden cardiac deaths with no previous history of heart disease, and PM_{10} affects all cardiovascular deaths and sudden cardiac deaths equally:

  - 462 sudden cardiac deaths brought forward out of 3,129 all cause deaths brought forward (15%)

b) If 15% of all cardiovascular deaths are sudden cardiac deaths with no previous history of heart disease, and PM_{10} affects all cardiovascular deaths and sudden cardiac deaths equally:

  - 278 sudden cardiac deaths brought forward out of 3,129 all cause deaths brought forward (9%)

9. Conclusions:

- Assuming 25% of all cardiovascular deaths are sudden cardiac deaths with no previous history of heart disease, this corresponds to either 16% or 15% of all deaths brought forward, depending on how ‘all deaths brought forward’ is calculated.
- Assuming 15% of all cardiovascular deaths are sudden cardiac deaths with no previous history of heart disease, this corresponds to either 10% or 9% of all deaths brought forward, depending on how ‘all deaths brought forward’ is calculated.

A3.1 Background

1. This annex provides the impacts and values (per tonne) used in the damage cost methodology for this report. Tables A3.1 – A3.3 present these for three pollutants: PM_{10}, NO_X and SO_2 based on a 1-year reduction in the pollutant level. Note that NO_X and SO_2 pollutants can have both direct effects and indirect effects via formation of secondary particles: NO_X can also have indirect effects via the formation of ozone, but these have not been included in the damage costs (in this version) due to non-linearity.[1] The damage costs shown are for emissions in the year 2010, discounted back to 2005.

2. Since the publication of the Third Report, there have been changes in key assumptions which have affected this annex. First is the assumption relating to secondary PM 50% assumption which has changed the actual damage costs to be used in cost benefit and sensitivity analysis. Also different hazard rate sensitivities have been used, the range of coefficients is now 1%, 6% and 12% and as such the cost values have changed.

3. The methodology for the estimation of the damage costs is detailed in an accompanying document 'Damage Costs for Air Pollution'.[2] Though this document explains the methodology behind the use of damage costs, it must be reminded that the document does not take account of the new 50% assumption regarding secondary PM. As explained in that document, damage costs (impacts and values per tonne of pollutant) have been estimated for a number of different pollutants (PM_{10}, NO_X, SO_2 and VOCs). For PM_{10}, damage costs have also been estimated by sector. Analysis has been undertaken for an annual 'pulse' change in emissions as well as for 5 year, 20 year and 100 year sustained changes in emissions.

4. The cost benefit analysis for the AQS has only made use of the annual pulse damage costs for PM_{10}, NO_X and SO_2, therefore only these are presented in this annex. For PM_{10}, only the road transport sectoral estimates are shown here. The analysis for the AQS review has also used PM_{10} damage costs for the domestic and electricity supply sectors; these can be estimated by applying a factor of 0.58 and 0.05 respectively.

5. The range of damage cost estimates (from low to high) incorporates a number of different assumptions:

- Different concentration-response functions for the chronic mortality effect of particles i.e. a low estimate of 1% per $10\mu g.m^{-3}$, a central estimate of 6% per $10\mu g.m^{-3}$ and a high estimate of 12% per $10\mu g.m^{-3}$

- Different lag times for the chronic mortality effect of particles (i.e. zero year lag, 40 year lag). It can be seen from Table A3.1 – A3.3 that, for the annual pulse, the life years lost per tonne of PM_{10} are larger when the 40 year lag assumption is used

[1] At current concentrations, reductions in NO_x in urban areas tends to increase ozone (leading to health impacts), because the scavenging of ozone by NO occurs. However, large enough reductions in NO_x emissions will lead to reductions in ozone concentrations. The omission of NO_x ozone effects is not considered to be significant to the overall NO_x damage costs used in the analysis here, as senitivity runs have found that these effects (expressed in monetary values) are around one to two orders of magnitude lower than the other NO_x effects.

[2] Watkiss et al (2006). Published alongside the IGCB report at http://www.defra.gov.uk/environment/airquality/strategy/igcb/index.htm

(see Chapter 2.5 for an explanation). However, when these impacts are valued, incorporating the discounting of future values, the 40 year lag damage costs are lower than those assuming a zero year lag; and

- A range of monetary values included in the central values recommended for hospital admissions (a single value of £29,000 (2004 prices) was used for the value of a life year).

6. The low damage cost estimate presented here incorporates the lowest value for each of these assumptions i.e. 1% per 10µg.m^{-3}, 40 year lag and low central valuation for the chronic mortality effects of particles, and low central valuation for all other health effects. The high damage cost estimate incorporates the highest value for each of these assumptions i.e. 12% per 10µg.m^{-3}, 0 year lag and high central valuation for chronic mortality effects of particles, and high central valuation for all other health effects.

7. A large number of caveats are associated with the potential use of these damage cost numbers. These are detailed in the accompanying report and should be borne in mind when assessing the results that have been estimated using these damage costs.

Table A3.1: Impacts and values per tonne of PM_{10}: based on 1 year reduction in PM_{10} (specific to to road transport sector (average) only)

Summary		**Annualised value/tonne p.a.**	
		Low estimate[3]	*High estimate*[4]
1% PM concentration response function		6,221	9,034
6% PM concentration response function		34,753	50,439
12% PM concentration response function		68,911	100,126
Detailed breakdown of impacts and values			
	Health benefits/ tonne	*Annualised value £/tonne p.a*	
Years of life lost over 100 years[5]			
1% concentration response, no lag	0.343	8,281	
6% concentration response, no lag	2.059	49,686	
12% concentration response, no lag	4.116	99,372	
1% concentration response, 40 year lag	0.373	5,706	

[3] Low estimate assumes 1% per 10µg.m^{-3}, 40 year lag and low central valuation for chronic PM effects, and low central valuation for other health effects.

[4] High estimate assumes 12% per 10µg.m^{-3}, zero lag and high central valuation for chronic PM effects, and high and high central valuation for other health effects.

[5] The chronic mortality health effect of particles is presented as total number of years lost over 100 years from changes in pollution over one year. All other health impacts and all values (including those for chronic mortality) are expressed in per annum terms.

6% concentration response, 40 year lag	2.238	34,238
12% concentration response, 40 year lag	4.476	68,472
	Health benefits/ tonne	*Annualised value £/tonne p.a*
Respiratory hospital admission (p.a.)	0.017	
Low Valuation		31
High Valuation		151
Cardiovascular hospital admissions (p.a.)	0.017	
Low Valuation		33
High Valuation		153
Non-health benefits		
PM soiling		450

Table A3.2: Impacts and values per tonne of NO_X: based on 1 year reduction in NO_X

Summary	**Annualised value/tonne p.a.**	
	Low estimate[6]	High estimate[7]
1% PM concentration response function	115	171
6% PM concentration response function	681	993
12% PM concentration response function	1,362	1,980

Detailed breakdown of impacts and values		
NO_X as PM	*Health benefits/ tonne*	*Annualised value £/tonne p.a* **Years of life lost over 100**
years[8]		
1% concentration response, no lag	0.007	165
6% concentration response, no lag	0.041	987
12% concentration response, no lag	0.082	1,974
1% concentration response, 40 year lag	0.007	113
6% concentration response, 40 year lag	0.044	680
12% concentration response, 40 year lag	0.089	1,360
Respiratory hospital admission (p.a.)	0.001	

6 Low estimate assumes 1% per 10µg.m^{-3}, 40 year lag and low central valuation for chronic PM effects, and low central valuation for other health effects.

7 High estimate assumes 12% per 10µg.m^{-3}, zero lag and high central valuation for chronic PM effects, and high and high central valuation for other health effects.

8 The chronic mortality health effect of particles is presented as total number of years lost over 100 years from changes in pollution over one year. All other health impacts and all values (including those for chronic mortality) are expressed in per annum terms.

Low Valuation		1
High Valuation		3
NO_X as PM	*Health benefits/ tonne*	*Annualised value £/tonne p.a* **Years of life lost over 100**
Cardiovascular hospital admissions (p.a.)	0.001	
Low Valuation		1
High Valuation		3
Ozone – no threshold		
Deaths Brought Forward (p.a.)	(0.004)	
Low Valuation		(9)
High Valuation		(56)
Respiratory Hospital Admissions (p.a.)	(0.005)	
Low Valuation		(8)
High Valuation		(78)
Ozone – 50ppb threshold		
Deaths Brought Forward (p.a.)	(0.001)	
Low Valuation		(1)
High Valuation		(8)
Respiratory Hospital Admissions (p.a.)	(0.001)	
Low Valuation		(1)
High Valuation		(10)

Table A3.3: Impacts and values per tonne of SO_2: based on 1 year reduction in SO_2

Summary	**Annualised value/tonne p.a.**	
	Low estimate[9]	*High estimate*[10]
1% PM concentration response function	368	476
6% PM concentration response function	1,208	1,695
12% PM concentration response function	2,217	3,158

9 Low estimate assumes 1% per 10µg.m^{-3}, 40 year lag and low central valuation for chronic PM effects, and low central valuation for other health effects.

10 High estimate assumes 12% per 10µg.m^{-3}, zero lag and high central valuation for chronic PM effects, and high and high central valuation for other health effects.

Detailed breakdown of impacts and values		
SO_2 as PM	*Health benefits/ tonne*	*Annualised value £/tonne p.a*
Years of life lost over 100 years[11]		
1% concentration response, no lag	0.010	244
6% concentration response, no lag	0.060	1,463
12% concentration response, no lag	0.121	2,926
1% concentration response, 40 year lag	0.011	168
6% concentration response, 40 year lag	0.066	1,008
12% concentration response, 40 year lag	0.132	2,016
Respiratory hospital admission (p.a.)	0.001	
Low Valuation		1
High Valuation		4
Cardiovascular hospital admissions (p.a.)	0.001	
Low Valuation		1
High Valuation		4
SO_2 as a gas		
Deaths brought forward (p.a.)	0.002	
Low Valuation		6
High Valuation		17
Respiratory hospital admissions (p.a.)	0.002	
Low Valuation		4
High Valuation		17
Non-health benefits		
SO_2 material damage		189

[11] The chronic mortality health effect of particles is presented as total number of years lost over 100 years from changes in pollution over one year. All other health impacts and all values (including those for chronic mortality) are expressed in per annum terms.

A4.1 Introduction

1. The European Commission instigated a detailed cost benefit analysis of the proposals being adopted under the Clean Air for Europe (CAFE) thematic strategy. This followed similar principles to the IGCB methodology i.e. the impact-pathway approach to assess the costs and benefits of potential ambition levels. The methodology and results of the CAFE CBA can be found at www.cafe-cba.org.

2. There are a number of key differences between the CBA undertaken for CAFE and that undertaken here for the review of the AQS. This section cannot explore all the differences, but aims to highlight the most important ones and assess their impact.

3. The CAFE analysis incorporates a wider range of health impacts than those included in this analysis. For example, PM infant mortality, Accident and Emergency visits for respiratory illness, GP visits for asthma and lower respiratory symptoms, and restricted activity days are all included in the CAFE analysis. The IGCB methodology does not include these effects; it is based on recommendations from COMEAP and these do not currently recommend the inclusion of these effects. In some cases, this is because the evidence is not considered to be sufficiently robust, in other cases there may be no UK-specific evidence on which to base recommendations.

4. Within the IGCB analysis, values are uplifted each year to reflect the assumption that willingness to pay will increase in line with long term economic growth. No such uplifts are applied in the CAFE analysis.

5. The other key differences relate to the way in which the PM chronic effects have been quantified and valued for:

   - Concentration-response functions: the CAFE analysis uses a 6% hazard rate per 10µg.m^{-3} $PM_{2.5}$, for its central analysis, with a 4% hazard rate used as sensitivity. This is based on WHO recommendations.[1] The IGCB analysis presented in this report estimates the benefits using a 6% coefficient with 1% and 12% coefficients as sensitivities. As discussed elsewhere, COMEAP has recently published an interim statement suggesting a preferred coefficient of 6% per 10µg.m^{-3} $PM_{2.5}$, consistent with the CAFE analysis. A draft full report from COMEAP discussing the evidence leading to this recommendation has just been published.[2]

   - The CAFE analysis applies the PM hazard rate to anthropogenic $PM_{2.5}$ data. In contrast, the IGCB methodology applies the PM hazard rates direct to PM_{10} data (specifically to the change in PM_{10} data).

   - Lag effects: the IGCB analysis shows a range for the chronic mortality impacts, reflecting different assumptions regarding the lag between changes in pollution and change in health impacts. The lower bound of the range assumes a 40 year

[1] Recommendations of UNECE/WHO Task Force on Health (TFH) (UNCEE/WHO, 2003). Available at http://www.unece.org/env/documents/2003/eb/wg1/eb.air.wg1.2003.ll.pdf

[2] Department of Health (2007) Committee on the Medical Effects of Air Pollutants 'Long-term Exposure to Air Pollution: Effect on Mortality' Draft report for technical comment.
http://www.advisorybodies.doh.gov.uk/comeap/statementsreports/longtermeffectsmort2007.pdf"

lag between PM concentrations and chronic mortality effects; the upper bound assumes a zero year lag. The CAFE analysis assumes no lag effect.

- The CAFE analysis presents the chronic health effects not only in terms of life years lost but also in terms of premature deaths. It uses valuation based on the value of a life year (for life years lost) and the value of a statistical life (for premature deaths). For each of these approaches, both the median and mean values from the NewExt study (2004) have been used i.e. four different estimates have been presented. The IGCB methodology recommends the use of life years only; in addition, the central VOLY used in this analysis (£29,000, in 2004 prices) is relatively close to the median VOLY used in the CAFE analysis (€52,000, in 2000 prices).

6. The effect of these differences has been quantified as far as possible, using one of the combined scenarios for comparison and the generalised results are as follows.

Table A4.1: Comparison between the IGCB and CAFE methodologies

Difference	Effect
Concentration-response functions	CAFE and IGCB both use 6% change in hazard rates as the preferred estimate. However, considering the full range of concentration-response functions, a 12% coefficient increases the PM chronic mortality estimates by almost a factor of two compared to a 6% coefficient. The 1% coefficient reduces the PM chronic mortality estimates by a factor of 6.[3]
Application of PM dose response functions to PM_{10} vs. $PM_{2.5}$	PM chronic mortality estimates using PM_{10} approximately 1.3 – 1.7 times greater than estimates using $PM_{2.5}$
Lag effects	CAFE and IGCB both use assumptions of no lag between changes in PM and changes in chronic mortality. However, IGCB also assumes a 40-year lag as well. This has the effect of approximately halving the PM chronic mortality estimates compared to a no lag assumption.
CAFE VOLY/VOSL estimates	The VOLY used in the IGCB methodology is broadly consistent with the median VOLY used in the CAFE analysis. However, CAFE also uses a VOSL estimate as well. Using the CAFE mean VOSL estimate has the effect of increasing the PM chronic mortality estimates by a factor of approximately four.
Uplift	Using the IGCB uplift increases the overall annualised PM chronic mortality estimates by a factor of approximately two, when the chronic effects are assessed over a 100 year period.

[3] In the main IGCB analysis linear scaling is used as a suitable approximation. However, for the larger coefficients in the sensitivity analysis non-linear scaling has also been used. Using linear scaling as an approximation overestimates the number of life years gained by approximately 2-3% for the central 6% coefficient and by approximately 4-6% for the 12% coefficient.

	Name of measure	Description of measure	When it applies	Where it applies	Period of benefits modelling	Basis of quantification
A	Euro standards 5/VI – low intensity	This measure proposes: • 20% reduction in NO_X from all new diesel LDVs (Euro 5) • 90% reduction in PM emissions from all new diesel LDVs (Euro 5) • 50% reduction in NO_X from all new diesel HDVs (Euro VI)	This measure is introduced from: 2010 for cars and LDVs 2013 for HDVs	This measure applies to all EU countries	Modelled over 100 years between 2010 – 2109	Concentrations data
A2	Euro standards 5/6/VI – revised scenario	This measure proposes: • 28% reduction in NO_X from all new diesel LDVs in 2010 (Euro 5) • 72% reduction in NO_X from all new diesel LDVs in 2015 (Euro 6) • 13% reduction in NO_X from all new petrol LDVs by 2010 (Euro 5) • 90% reduction in PM from all new diesel LDVs in 2010 (Euro 5) • 50% reduction in NO_X from all new diesel HDVs (Euro VI)	This measure is introduced from: 2010 for LDVs (Euro 5) 2015 for LDVs (Euro 6) 2013 for HDVs	This measure applies to all EU countries	Modelled over 100 years between 2010 – 2109	Concentrations data

	Name of measure	Description of measure	When it applies	Where it applies	Period of benefits modelling	Basis of quantification
B	New Euro standard 5/6/VI – High intensity	This measure proposes: • 50% reduction in NO_X from all new petrol LDVs by 2010 (Euro 5) • 40% reduction in NO_X from all new diesel LDVs in 2010 (Euro 5) • 68% reduction in NO_X from all new diesel LDVs in 2015 (Euro 6) • 75% reduction in NO_X for all new HDVs (Euro VI) • 90% reduction in PM for all new diesel vehicles (HDVs and LDVs); (Euro 5/VI)	This measure is introduced from: 2010 for LDVs for initial reduction in NO_X (Euro 5) 2015 for LDVs for tighter reduction in NO_X (Euro 6) 2013 for HDVs	This measure applies to all EU countries	Modelled over 100 years between 2010 – 2109	Concentrations data

	Name of measure	Description of measure	When it applies	Where it applies	Period of benefits modelling	Basis of quantification
C	Programme of incentives for early uptake of Euro 5/V/VI standards	This measure assumes that a programme of incentives is introduced for early introduction of Euro 5/V/VI. This measure is to be implemented based on Measure A, i.e. the policy reverts back to Measure A after the incentives have taken effect. The uptake rates of these incentives are: 2007: 25% Euro 5 LDVs, 15% Euro V HDVs 2008: 50% Euro 5 LDVs, 23% Euro V HDVs 2009: 75% Euro 5 LDVs (Euro V now mandatory for HDVs) 2010: 25% Euro VI HDVs (Euro 5 now mandatory for LDVs) 2011: 50% Euro VI HDVs 2012: 75% Euro VI HDVs 2013: Euro VI now mandatory for HDVs	This measure is introduced from: 2007 for LDVs (Euro 5) 2010 for HDVs (Euro VI)	This measure applies to the UK	Modelled over 100 years between 2010 – 2109	Concentrations data

	Name of measure	Description of measure	When it applies	Where it applies	Period of benefits modelling	Basis of quantification
C2	Programme of Incentives for early uptake of Euro 5/6/V/VI standards (revised scenario)	This measure proposes a programme of incentives based on the new Measure A2 to introduce the Euro standards 5/V/VI. The impacts of the measure revert back to Measure A2 once the new standards become mandatory. The uptake rates of these incentives are: 2007: 0% LDVs and HDVs 2008: 33% LDVs (Euro 5), 47.5% HDVs (Euro V), 0% HDVs (Euro VI) 2009: 66% LDVs (Euro 5), 0% HDVs (Euro VI), Euro V now mandatory for HDVs. 2010: Euro 5 now mandatory for LDVs, 25% for HDVs (Euro VI) 2011: 50% HDVs (Euro VI) 2012: 75% HDVs (Euro VI) 2013: Euro VI now mandatory for HDVs, 33% Euro 6 LDVs 2014: 66% Euro 6 LDVs 2015: Euro 6 now mandatory for LDVs	This measure is introduced from: 2007 for LDVs (Euro 5) 2007 for HDVs (Euro V) 2010 for HDVs (Euro VI) 2013 for LDVs (Euro 6)	This measure applies to the UK	Modelled over 100 years between 2010 – 2109	Concentrations data

	Name of measure	Description of measure	When it applies	Where it applies	Period of benefits modelling	Basis of quantification
D	Programme of incentives to phase out the most polluting vehicles (divided into two sub-measures)	**Measure D1:** This scenario models scrappage of all pre-Euro cars (emissions only modelled) **Measure D2:** This scenario models scrappage of all pre-Euro and Euro 1 cars (concentrations modelling) All pre-Euro cars in Measure D1 and the Euro 1 passengers in Measure D2 are assumed to be scrapped at rates of: 25% by 2007, 50% by 2008 and 100% by 2009 and replaced by Euro IV	This measure is introduced from 2007	This measure applies to the UK	**D1:** Modelled over 5 years between 2010 – 2014 **D2:** Modelled over 10 years between 2010 – 2019	**D1:** Emissions data **D2:** Concentrations data
E	Programme of incentives to increase penetration of low emission vehicles (LEVs)	Petrol LEVs are assumed to deliver 38% reduction in NOx and 34% reduction in CO_2 compared to Euro 4 petrol cars. Penetration of petrol LEVs assumed at 10% by 2010; 25% by 2020. Diesel LEVs assumed to deliver 80% reduction in NO_X, 92% reduction in PM and 29% reduction in CO_2 compared to Euro 4 diesel cars. Penetration of diesel LEV assumed to at 5% by 2010; 20% by 2020. It is assumed that petrol LEVs replace non-LEV petrol cars, diesel LEVs replace non-LEV diesel cars	This measure is introduced from 2006	This measure applies to the UK	Modelled over 100 years between 2010 – 2109	Concentrations data

	Name of measure	Description of measure	When it applies	Where it applies	Period of benefits modelling	Basis of quantification
F	Impact of national road pricing scheme on air quality	This measure is based on the work that was done for the Road Pricing Feasibility study. Emissions based on the analytical work that assumed marginal cost pricing, using 10 charges capped at 80p. The emissions from the modelling have then been used for projections from 2015.	This measure is introduced from 2015	This measure applies to the UK	Modelled over 100 years between 2010 – 2109	Concentrations data
G	Low emission zones (divided into three sub measures)	Measures for London: **Measure G1:** 2007 – HGVs adopt Euro II + RPC **Measure G2:** 2010 – HGVs adopt Euro III + RPC **Measure G3:** 2010 – HGVs adopt Euro II + RPC replicated for seven urban areas outside London.	This measure is introduced from: **G1:** 2007 **G2:** 2010 **G3:** 2010 for seven largest urban areas outside London	**G1:** London **G2:** London **G3:** Seven largest urban areas outside London	**G1:** Modelled over 8 years between 2007 – 2014 **G2:** Modelled over 5 years between 2010 – 2014 **G3:** Modelled over 8 years between 2010 – 2017	Emissions data
H	Retrofit (Diesel particulate Filters) DPFs on HGVs and captive fleets (buses and coaches) It is divided into three sub measures.	**Measure H1:** 65% pre-Euro I to Euro IV HDVs retrofitted with Diesel Particulate Filters (DPFs) + Fuel Borne Catalysts (FBCs) by 2010 **Measure H2:** 20% pre-Euro I to Euro IV HDVs retrofitted with Pt-coated DPFs by 2010. **Measure H3:** 35% pre-Euro I to Euro IV HDVs retrofitted with Pt-coated DPFs by 2010	This measure is introduced from 2006	This measure applies to the UK	**H1:** Modelled over 13 years between 2010 – 2022 **H2:** Modelled over 13 years between 2010 – 2022 **H3:** Modelled over 13 years between 2010 – 2022	Emissions data

	Name of measure	Description of measure	When it applies	Where it applies	Period of benefits modelling	Basis of quantification
I	Domestic consumption: switch from coal to natural gas or oil	The switch from coal to natural gas (70% in GB) or to oil (30% in GB) is assumed. However in Northern Ireland a larger switch from coal to oil (70%) and smaller switch to gas (30%) is assumed.	This measure is fully implemented by 2010	This measure applies to the UK	Modelled over 15 years between 2010 – 2024	Emissions data
J	Domestic consumption: Product standards for gas fired appliances which require tighter NO_X emission standards	New appliances post 2008 fitted to at least CEN 483 Class 4 for gas fired appliances. Replacement rate of 5% of the boilers assumed per year, i.e. assumes a 20 year lifespan of existing older 'high NO_X' boilers.	This measure is introduced from 2008	This measure applies to all EU countries	Modelled over 100 years between 2010 – 2109	Concentrations data
K	Large combustion plants measure	**Measure K1:** Brings forward to 2010 the implantation of SCR on coal fired power stations with generating capacity > 300 MW. **Measure K2:** Assumes SCR on gas fired power stations, iron and steel plants and petrol refineries by 2010.	This measure is introduced from 2010	**K1:** This measure applies to the UK **K2:** This measure applies to all EU countries	**K1:** Modelled over 6 years between 2010 – 2015 **K2:** Modelled over 100 years between 2010 – 2109	**K1:** Emissions data **K2:** Concentrations data
L	Small combustion plants measure	50% reduction in NO_2 and SO_2 in small combustion plants (20-50 MW). This measure is due to be applied following a potential EU Small Combustion Plant Directive or revision of existing IPPC or LCPD Directive in 2008.	This measure is due to be implemented in 2013	This measure applies to all EU countries	Modelled over 100 years between 2010 – 2109	Concentrations data

	Name of measure	Description of measure	When it applies	Where it applies	Period of benefits modelling	Basis of quantification
M	Reducing national VOC emissions by 10%	The various measures used to achieve this target are: Petrol stations Stage II controls (>3,000 m^3 throughput) Chemical and man made fibre production: • Thermal oxidation • Road tanker vapour recovery • Storage tank replacement programme (TRM) • Leak detection & repair (LDAR) – BAU • Second stage vapour recovery unit (VRU) • Cryogenic condensation (CC) Offshore loading of crude oil: • Modification to shuttle tankers (MST) • Modification to floating production, storage and off take vessels (MFPSO) • Vapour recovery unit (from ship loading)	This measure is introduced from 2010	This measure applies to the UK	Modelled over 100 years between 2010 – 2109	Concentrations data

	Name of measure	Description of measure	When it applies	Where it applies	Period of benefits modelling	Basis of quantification
N	Shipping measure through IMO	Requirements on global fleet (for all ships >100 tonnes) to: • Use 1% rather than 1.5% Sulphur fuel from 2010 (applies to old and new vessels from 2010) • Reduce NO_X emissions by 25% from new ships from 2010 The introduction rate of new ships is assumed to be 1/30th of fleet per year.	The scheme is due to start from 2010	This measure applies to the UK and all maritime	Modelled over 100 years between 2010 – 2109	Concentrations data
O	Combined measure: C + E	See Measures C and E above			Modelled over 100 years between 2010 – 2109	Concentrations data
P	Combined measure: C + L	See Measures C and L above			Modelled over 100 years between 2010 – 2109	Concentrations data
Q	Combined measure: C + E + L	See measures C, E and L above			Modelled over 100 years between 2010 – 2109	Concentrations data
R	Combined measure; C2 + E + N	See Measures C2, E and N above			Modelled over 100 years between 2010 – 2109	Concentrations data

Annex 6 – Monetary cost-benefit analysis results at devolved administration level

A6.1 Introduction

1. This annex presents the quantified health impacts, and the annual present values of these impacts, at devolved administration level. A full discussion of the assumptions used to quantify and value these impacts is presented in Chapter 3 in more detail.

2. The following sections set out the health impacts and annualised present values of these impacts, in line with the results presented in Chapter 3:

   - **Section A6.2** – England
   - **Section A6.3** – Scotland
   - **Section A6.4** – Wales
   - **Section A6.5** – Northern Ireland

3. Results are only shown for those measures that have been modelled at concentration levels. In addition, only the major health impacts are presented: devolved administration level analysis of the impacts on carbon, SO_2, crop yields and damage to buildings and materials is not presented in this annex.

A6.2 England

Table A6.1: Quantified impacts of additional measures in England[a]

Measure	PM life years saved (000s) – 1%[b]	PM life years saved (000s) – 6%	PM life years saved (000s) – 12%[b]	PM – RHA (p.a.)	PM – CHA (p.a.)	Ozone mortality (p.a.)	Ozone RHA (p.a.)
Measure A (Euro low)	183 – 350	1,100 – 2,099	2,200 – 4,198	216	217	(260) – (24)	(300) – (28)
Measure A2 (Revised scenario)	197 – 377	1,185 – 2,261	2,369 – 4,521	197	197	(347) – (10)	(401) – (11)
Measure B (Euro high)	182 – 347	1,091 – 2,083	2,182 – 4,165	309	309	(547) – (45)	(632) – (52)
Measure C (Early Euro low)	158 – 291	946 – 1,748	1,893 – 3,497	228	229	(274) – (27)	(317) – (31)
Measure C2 (Revised scenario)	216 – 405	1,295 – 2,427	2,591 – 4,855	216	207	(370) – (42)	(428) – (48)
Measure E (LEV)	12 – 23	74 – 141	148 – 282	16	16	(41) – (7)	(44) – (7)
Measure F (Road Pricing)	31 – 59	186 – 354	371 – 708	33	33	–	–

Measure	PM life years saved (000s) – 1%[b]	PM life years saved (000s) – 6%	PM life years saved (000s) – 12%[b]	PM – RHA (p.a.)	PM – CHA (p.a.)	Ozone mortality (p.a.)	Ozone RHA (p.a.)
Measure J (Domcom NO_X)	7 – 14	43 – 83	87 – 165	14	14	(53) – (7)	(62) – (8)
Measure K2 (LCP)	23 – 44	137 – 261	274 – 522	45	45	(113) – (19)	(130) – (22)
Measure L (SCP)	9 – 18	55 – 105	110 – 211	19	19	(30) – (5)	(34) – (6)
Measure M (VOCs)	–	–	–	–	–	3 – 9	4 – 10
Measure N (Shipping)	86 – 164	515 – 983	1,030 – 1,965	170	170	–	–
Measure O (Early Euro low + LEV)	208 – 387	1,247 – 2,323	2,495 – 4,646	235	235	(306) – (32)	(353) – (37)
Measure P (Early Euro low + SCP)	214 – 398	1,281 – 2,387	2,562 – 4,775	247	247	(303) – (31)	(350) – (36)
Measure Q (Early Euro low + LEV + SCP)	217 – 405	1,303 – 2,428	2,605 – 4,856	254	254	(335) – (36)	(386) – (42)
Measure R (C2 + LEV + Shipping)	302 – 569	1,812 – 3,413	3,624 – 6,826	292	293	(354) – (41)	(409) – (47)

a Data presented in the table in brackets represents a negative impact – for ozone impacts this reflects the increase in population weighted ozone concentrations presented in the previous table.

b All life years are estimated over a 100 year period, except for Measure D2 which is estimated over a 10 year period

Table A6.2: Annual present values of impacts for additional measures in England[a] £M p.a.

Measure	PM life years saved (000s) – 1%[b]	PM life years saved (000s) – 6%[b]	PM life years saved (000s) – 12%[b]	PM – RHA (p.a.)	PM – CHA (p.a.)	Ozone mortality (p.a.)	Ozone RHA (p.a.)
Measure A (Euro low)	78 – 182	466 – 1,094	931 – 2,188	1 – 3	1 – 3	(4) – (0.11)	(4) – (0.08)
Measure A2 (Revised scenario)	84 – 196	501 – 1,178	1,003 – 2,356	1 – 3	1 – 3	(4) – (0.06)	(6) – (0.05)
Measure B (Euro high)	77 – 181	462 – 1,085	924 – 2,171	1 – 5	1 – 5	(8) – (0.21)	(9) – (0.15)
Measure C (Early Euro low)	67 – 152	401 – 911	801 – 1,822	1 – 3	1 – 3	(3) – (0.09)	(4) – (0.07)

Measure	PM life years saved (000s) – 1%[b]	PM life years saved (000s) – 6%[b]	PM life years saved (000s) – 12%[b]	PM – RHA (p.a.)	PM – CHA (p.a.)	Ozone mortality (p.a.)	Ozone RHA (p.a.)
Measure C2 (Revised scenario)	91 – 211	548 – 1,264	1,096 – 2,530	1 – 3	1 – 3	(5) – (0.06)	(7) – (0.05)
Measure E (LEV)	5 – 12	31 – 147	62 – 147	0.05 – 0.25	0.05 – 0.25	(0.54) – (0.03)	(0.62) – (0.02)
Measure F (Road Pricing)	13 – 31	79 – 185	157 – 369	0.11 – 0.52	0.11 – 0.52	–	–
Measure J (Domcom NO_X)	3 – 7	18 – 43	37 – 86	0.05 – 0.22	0.05 – 0.22	(0.76) – (0.03)	(0.86) – (0.02)
Measure K2 (LCP)	10 – 23	58 – 136	116 – 272	0.20 – 1	0.22 – 1	(2) – (0.09)	(3) – (0.09)
Measure L (SCP)	4 – 9	23 – 55	47 – 110	0.07 – 0.32	0.07 – 0.32	(1) – (0.05)	(1) – (0.04)
Measure M (VOCs)	–	–	–	–	–	0.01 – 0.12	0.01 – 0.16
Measure N (Shipping)	36 – 85	218 – 512	436 – 1,024	1 – 3	1 – 3	–	–
Measure O (Early Euro low + LEV)	88 – 206	528 – 1,210	1,056 – 2,421	1 – 3	1 – 3	(3) – (0.12)	(4) – (0.09)
Measure P (Early Euro low + SCP)	90 – 207	542 – 1,244	1,085 – 2,488	1 – 4	1 – 4	(3) – (0.12)	(4) – (0.09)
Measure Q (Early Euro low + LEV + SCP)	92 – 211	551 – 1,265	1,102 – 2,560	1 – 4	1 – 4	(4) – (0.14)	(5) – (0.11)
Measure R (C2 + LEV + Shipping)	128 – 296	767 – 1,779	1,533 – 3,557	1 – 5	1 – 5	(5) – (0.01)	(6) – 0

a Numbers in brackets represent negative values.

A6.3 Scotland

Table A6.3: Quantified impacts of additional measures in Scotland[a]

Measure	PM life years saved (000s) – 1%[b]	PM life years saved (000s) – 6%[b]	PM life years saved (000s) – 12%[b]	PM – RHA (p.a.)	PM – CHA (p.a.)	Ozone mortality (p.a.)	Ozone RHA (p.a.)
Measure A (Euro low)	12 – 23	73 – 139	146 – 278	14	14	(9) – (1)	(10) – (1)
Measure A2 (Revised scenario)	13 – 24	76 – 146	153 – 291	13	13	(10) – (1)	(11) – (1)
Measure B (Euro high)	15 – 28	89 – 171	179 – 341	18	18	(16) – 0	(19) – 0
Measure C (Early Euro low)	14 – 25	81 – 151	162 – 302	14	14	(10) – (1)	(11) – (1)
Measure C2 (Revised scenario)	14 – 26	83 – 156	167 – 312	13	13	(10) – (2)	(12) – (2)
Measure E (LEV)	0.8 – 1.5	5 – 9	9 – 18	1	1	(2) – 0	(2) – 0
Measure F (Road Pricing)	1 – 3	8 – 16	17 – 32	1	1	–	–
Measure J (Domcom NO_X)	0.3 – 0.7	2 – 4	4 – 8	1	1	(4) – 0	(4) – (1)
Measure K2 (LCP)	1 – 2	7 – 12	13 – 25	2	2	(7) – (1)	(8) – (2)
Measure L (SCP)	0.5 – 0.9	3 – 5	6 – 11	1	1	(1) – 0	(2) – 0
Measure M (VOCs)	–	–	–	–	–	0 – 1	0 – 1
Measure N (Shipping)	5 – 9	27 – 52	55 – 105	9	9	–	–
Measure O (Early Euro low + LEV)	14 – 25	82 – 152	163 – 304	15	15	(11) – (1)	(13) – (1)
Measure P (Early Euro low + SCP)	14 – 26	82 – 154	163 – 308	15	15	(11) – (1)	(13) – (1)
Measure Q (Early Euro low + LEV + SCP)	14 – 26	85 – 158	169 – 315	16	16	(12) – (1)	(14) – (1)

Measure	PM life years saved (000s) – 1%[b]	PM life years saved (000s) – 6%[b]	PM life years saved (000s) – 12%[b]	PM – RHA (p.a.)	PM – CHA (p.a.)	Ozone mortality (p.a.)	Ozone RHA (p.a.)
Measure R (C2 + LEV + Shipping)	18 – 35	111 – 209	222 – 417	18	18	(7) – (2)	(7) – (2)

a Data presented in the table in brackets represents a negative impact – for ozone impacts this reflects the increase in population weighted ozone concentrations presented in the previous table.

b All life years are estimated over a 100 year period, except for Measure D2 which is estimated over a 10 year period

Table A6.4: Annual present values of impacts for additional measures in Scotland[a] £M p.a.

Measure	PM life years saved (000s) – 1%[b]	PM life years saved (000s) – 6%[b]	PM life years saved (000s) – 12%[b]	PM – RHA (p.a.)	PM – CHA (p.a.)	Ozone mortality (p.a.)	Ozone RHA (p.a.)
Measure A (Euro low)	5 – 12	31 – 72	62 – 145	0.04 – 0.21	0.05 – 0.21	(0.13) – 0	(0.16) – 0
Measure A2 (Revised scenario)	5 – 13	32 – 76	65 – 152	0.04 – 0.20	0.04 – 0.20	(0.13) – 0	(0.17) – 0
Measure B (Euro high)	6 – 15	38 – 89	76 – 178	0.06 – 0.28	0.06 – 0.28	(0.23) – 0	(0.29) – 0
Measure C (Early Euro low)	6 – 13	34 – 79	69 – 157	0.04 – 0.20	0.04 – 0.20	(0.16) – 0	(0.19) – 0
Measure C2 (Revised scenario)	6 – 14	35 – 81	71 – 163	0.04 – 0.20	0.04 – 0.20	(0.13) – 0	(0.19) – 0
Measure E (LEV)	0.3 – 0.8	2 – 5	4 – 9	0 – 0.01	0 – 0.01	(0.03) – 0	(0.04) – 0
Measure F (Road Pricing)	0.6 – 1.4	3 – 8	7 – 17	0 – 0.02	0.01 – 0.02	–	–
Measure J (Domcom NO_X)	0.1 – 0.3	1 – 2	2 – 4	0 – 0.01	0 – 0.01	(0.05) – 0	(0.07) – 0
Measure K2 (LCP)	0.5 – 1.1	3 – 6	6 – 13	0.01 – 0.05	0.01 – 0.05	(0.09) – (0.01)	(0.15) – (0.01)
Measure L (SCP)	0.2 – 0.5	1 – 3	2 – 6	0 – 0.02	0 – 0.02	(0.02) – 0	(0.03) – 0
Measure M (VOCs)	–	–	–	–	–	0 – 0.01	0 – 0.02
Measure N (Shipping)	2 – 5	12 – 27	23 – 55	0.05 – 0.15	0.03 – 0.15	–	–
Measure O (Early Euro low + LEV)	6 – 13	35 – 79	69 – 159	0.04 – 0.20	0.04 – 0.21	(0.18) – (0.01)	(0.21) – 0

Measure	PM life years saved (000s) – 1%[b]	PM life years saved (000s) – 6%[b]	PM life years saved (000s) – 12%[b]	PM – RHA (p.a.)	PM – CHA (p.a.)	Ozone mortality (p.a.)	Ozone RHA (p.a.)
Measure P (Early Euro low + SCP)	6 – 13	35 – 80	69 – 161	0.05 – 0.21	0.05 – 0.22	(0.17) – (0.01)	(0.21) – 0
Measure Q (Early Euro low + LEV + SCP)	6 – 14	36 – 82	72 – 164	0.05 – 0.22	0.05 – 0.22	(0.20) – (0.01)	(0.23) – 0
Measure R (C2 + LEV + Shipping)	8 – 18	47 – 109	94 – 217	0.06 – 0.29	0.06 – 0.29	(0.08) – 0	(0.11) – 0

a Numbers in brackets represent negative values.

A6.4 Wales

Table A6.5: Quantified impacts of additional measures in Wales[a]

Measure	PM life years saved (000s) – 1%[b]	PM life years saved (000s) – 6%[b]	PM life years saved (000s) – 12%[b]	PM – RHA (p.a.)	PM – CHA (p.a.)	Ozone mortality (p.a.)	Ozone RHA (p.a.)
Measure A (Euro low)	6 – 12	38 – 72	75 – 144	8	8	(8) – (1)	(9) – (1)
Measure A2 (Revised scenario)	7 – 13	42 – 80	84 – 160	6	7	(9) – 0	(10) – (1)
Measure B (Euro high)	8 – 16	51 – 97	101 – 193	12	12	(14) – 0	(17) – 0
Measure C (Early Euro low)	7 – 13	42 – 78	84 – 157	8	8	(8) – (1)	(9) – (1)
Measure C2 (Revised scenario)	8 – 14	47 – 86	95 – 172	7	7	(9) – (1)	(10) – 2)
Measure E (LEV)	0.4 – 0.8	3 – 5	5 – 10	1	1	(1) – 0	(1) – 0
Measure F (Road Pricing)	0.4 – 0.8	2 – 5	5 – 9	0	0	–	–
Measure J (Domcom NO_X)	0.3 – 0.6	2 – 4	4 – 8	1	1	(1) – 0	(2) – 0
Measure K2 (LCP)	1 – 2	6 – 12	12 – 24	2	2	(6) – (2)	(7) – (2)
Measure L (SCP)	0.4 – 0.8	3 – 5	5 – 10	1	1	(1) – 0	(1) – 0

Measure	PM life years saved (000s) – 1%[b]	PM life years saved (000s) – 6%[b]	PM life years saved (000s) – 12%[b]	PM – RHA (p.a.)	PM – CHA (p.a.)	Ozone mortality (p.a.)	Ozone RHA (p.a.)
Measure M (VOCs)	–	–	–	–	–	0 – 1	0 – 1
Measure N (Shipping)	4 – 8	25 – 48	50 – 95	8	8	–	–
Measure O (Early Euro low + LEV)	7 – 13	43 – 80	85 – 159	8	8	(9) – (1)	(11) – (1)
Measure P (Early Euro low + SCP)	7 – 14	45 – 83	89 – 167	9	9	(9) – (1)	(11) – (1)
Measure Q (Early Euro low + LEV + SCP)	8 – 14	45 – 84	91 – 169	9	9	(10) – (1)	(12) – (1)
Measure R (C2 + LEV + Shipping)	12 – 22	71 – 134	142 – 267	11	9	(6) – (1)	(7) – (1)

a Data presented in the table in brackets represents a negative impact – for ozone impacts this reflects the increase in population weighted ozone concentrations presented in the previous table.

b All life years are estimated over a 100 year period, except for Measure D2 which is estimated over a 10 year period.

Table A6.6: Annual present values of impacts for additional measures in Wales[a] £M p.a.

Measure	PM life years saved (000s) – 1%[b]	PM life years saved (000s) – 6%[b]	PM life years saved (000s) – 12%[b]	PM – RHA (p.a.)	PM – CHA (p.a.)	Ozone mortality (p.a.)	Ozone RHA (p.a.)
Measure A (Euro low)	3 – 6	16 – 37	32 – 75	0.02 – 0.12	0.03 – 0.12	(0.11) – 0	(0.14) – 0
Measure A2 (Revised scenario)	3 – 7	18 – 42	35 – 83	0.02 – 0.09	0.02 – 0.11	(0.11) – 0	(0.15) – 0
Measure B (Euro high)	4 – 8	21 – 50	43 – 101	0.04 – 0.18	0.04 – 0.18	(0.20) – 0	(0.25) – 0
Measure C (Early Euro low)	3 – 7	18 – 41	36 – 82	0.02 – 0.12	0.03 – 0.12	(0.12) – 0	(0.15) – 0
Measure C2 (Revised scenario)	3 – 7	20 – 45	40 – 90	0.02 – 0.11	0.02 – 0.11	(0.11) – 0	(0.16) – 0
Measure E (LEV)	0.1 – 0.4	1 – 3	2 – 5	0 – 0.01	0 – 0.01	(0.02) – 0	(0.02) – 0
Measure F (Road Pricing)	0.2 – 0.4	1 – 2	2 – 5	0 – 0.01	0 – 0.01	–	–

Measure	PM life years saved (000s) – 1%[b]	PM life years saved (000s) – 6%[b]	PM life years saved (000s) – 12%[b]	PM – RHA (p.a.)	PM – CHA (p.a.)	Ozone mortality (p.a.)	Ozone RHA (p.a.)
Measure J (Domcom NO_X)	0.1 – 0.3	1 – 2	2 – 4	0 – 0.01	0 – 0.01	(0.02) – 0	(0.03) – 0
Measure K2 (LCP)	0.4 – 1.0	5 – 12	10 – 25	0.01 – 0.04	0.01 – 0.05	(0.09) – (0.01)	(0.14) – (0.01)
Measure L (SCP)	0.2 – 0.4	3 – 6	5 – 12	0 – 0.02	0 – 0.02	(0.02) – 0	(0.02) – 0
Measure M (VOCs)	–	–	–	–	–	0 – 0.01	0 – 0.01
Measure N (Shipping)	2 – 4	11 – 25	21 – 50	0.03 – 0.14	0.03 – 0.14	–	–
Measure O (Early Euro low + LEV)	3 – 7	18 – 41	36 – 83	0.03 – 0.12	0.03 – 0.12	(0.13) – 0	(0.16) – 0
Measure P (Early Euro low + SCP)	3 – 7	19 – 43	38 – 87	0.03 – 0.13	0.03 – 0.14	(0.13) – 0	(0.17) – 0
Measure Q (Early Euro low + LEV + SCP)	3 – 7	19 – 44	38 – 88	0.03 – 0.14	0.03 – 0.14	(0.15) – (0.01)	(0.18) – (0)
Measure R (C2 + LEV + Shipping)	5 – 12	30 – 70	60 – 139	0.04 – 0.18	0.03 – 0.15	(0.08) – 0	(0.11) – 0

a Numbers in brackets represent negative values.

A6.5 Northern Ireland

Table A6.7: Quantified impacts of additional measures in Northern Ireland[a]

Measure	PM life years saved (000s) – 1%[b]	PM life years saved (000s) – 6%[b]	PM life years saved (000s) – 12%[b]	PM – RHA (p.a.)	PM – CHA (p.a.)	Ozone mortality (p.a.)	Ozone RHA (p.a.)
Measure A (Euro low)	3 – 5	15 – 29	31 – 59	3	3	(1) – 0	(1) – 0
Measure A2 (Revised scenario)	3 – 5	17 – 32	33 – 64	2	3	(1) – 0	0
Measure B (Euro high)	3 – 6	20 – 38	40 – 75	4	4	(1) – 1	(1) – 1
Measure C (Early Euro low)	3 – 5	17 – 32	34 – 64	3	3	(1) – 0	(1) – 0

Measure	PM life years saved (000s) – 1%[b]	PM life years saved (000s) – 6%[b]	PM life years saved (000s) – 12%[b]	PM – RHA (p.a.)	PM – CHA (p.a.)	Ozone mortality (p.a.)	Ozone RHA (p.a.)
Measure C2 (Revised scenario)	3 – 6	18 – 34	37 – 69	2	3	(1) – 0	(1) – 2
Measure E (LEV)	0.2 – 0.4	1 – 2	2 – 4	0	0	0	0
Measure F (Road Pricing)	0.1 – 0.2	0.5 – 1.1	1 – 2	0	0	–	–
Measure J (Domcom NO_X)	0.1 – 0.2	0.6 – 1.2	1 – 2	0	0	(1) – 0	(1) – 0
Measure K2 (LCP)	0.3 – 0.6	2 – 4	4 – 8	1	1	(2) – 0	(2) – 0
Measure L (SCP)	0.2 – 0.3	1 – 2	2 – 3	0	0	0	0
Measure M (VOCs)	–	–	–	–	–	0	0
Measure N (Shipping)	1 – 3	9 – 17	18 – 34	3	3	–	–
Measure O (Early Euro low + LEV)	3 – 5	17 – 32	35 – 65	3	3	(2) – 0	(2) – 0
Measure P (Early Euro low + SCP)	3 – 6	18 – 34	36 – 67	4	4	(1) – 0	(2) – 0
Measure Q (Early Euro low + LEV + SCP)	3 – 6	18 – 34	37 – 68	4	4	(2) – 0	(2) – 0
Measure R (C2 + LEV + Shipping)	5 – 9	27 – 51	54 – 102	4	5	(0) – 2	(0) – 2

a Data presented in the table in brackets represents a negative impact – for ozone impacts this reflects the increase in population weighted ozone concentrations presented in the previous table.

b All life years are estimated over a 100 year period, except for Measure D2 which is estimated over a 10 year period

Table A6.8: Annual present values of impacts for additional measures in Northern Ireland[a] £M p.a.

Measure	PM life years saved (000s) – 1%[b]	PM life years saved (000s) – 6%[b]	PM life years saved (000s) – 12%[b]	PM – RHA (p.a.)	PM – CHA (p.a.)	Ozone mortality (p.a.)	Ozone RHA (p.a.)
Measure A (Euro low)	1 – 3	7 – 15	13 – 31	0.01 – 0.05	0.01 – 0.05	(0.02) – 0	(0.02) – 0
Measure A2 (Revised scenario)	1 – 3	7 – 17	14 – 33	0.01 – 0.03	0.01 – 0.05	0	0

Measure	PM life years saved (000s) – 1%[b]	PM life years saved (000s) – 6%[b]	PM life years saved (000s) – 12%[b]	PM – RHA (p.a.)	PM – CHA (p.a.)	Ozone mortality (p.a.)	Ozone RHA (p.a.)
Measure B (Euro high)	1 – 3	8 – 20	17 – 39	0.01 – 0.07	0.01 – 0.07	(0.02) – 0	(0.02) – 0
Measure C (Early Euro low)	1 – 3	7 – 17	15 – 33	0.01 – 0.05	0.01 – 0.05	(0.02) – 0	(0.03) – 0
Measure C2 (Revised scenario)	1 – 3	8 – 18	15 – 36	0.01 – 0.03	0.01 – 0.05	0	0 – 0.01
Measure E (LEV)	0.1 – 0.2	0.5 – 1.1	1 – 2	0	0	(0.01) – 0	(0.01) – 0
Measure F (Road Pricing)	0.04 – 0.09	0.2 – 0.5	0.5 – 1.1	0	0	-	-
Measure J (Domcom NO_X)	0.05 – 0.11	0.3 – 0.7	0.6 – 1.3	0	0	(0.01) – 0	(0.01) – 0
Measure K2 (LCP)	0.1 – 0.3	1 – 2	2 – 4	0 – 0.01	0 – 0.01	(0.02) – 0	(0.03) – 0
Measure L (SCP)	0.1 – 0.2	0.4 – 0.9	0.7 – 1.8	0 – 0.01	0 – 0.01	0	0
Measure M (VOCs)	–	–	–	–	–	0	0
Measure N (Shipping)	0.6 – 1.5	4 – 9	7 – 18	0.01 – 0.05	0.01 – 0.05	–	–
Measure O (Early Euro low + LEV)	1 – 3	7 – 17	15 – 34	0.01 – 0.05	0.01 – 0.05	(0.03) – 0	(0.03) – 0
Measure P (Early Euro low + SCP)	1 – 3	8 – 18	15 – 35	0.01 – 0.05	0.01 – 0.05	(0.03) – 0	(0.03) – 0
Measure Q (Early Euro low + LEV + SCP)	1 – 3	8 – 18	15 – 36	0.01 – 0.05	0.01 – 0.05	(0.03) – 0	(0.03) – 0
Measure R (C2 + LEV + Shipping)	2 – 4	11 – 27	23 – 53	0.01 – 0.08	0.02 – 0.08	0.01 – 0.02	0.01 – 0.03

a Numbers in brackets represent negative values.

b All life years are estimated over a 100 year period, except for Measure D2 which is estimated over a 10 year period.

Annex 7 – Monte-Carlo Uncertainty Analysis of AQS Measures[1]

A7.1 Executive Summary

1. In appraisal, it is good practice to look at the uncertainties in the analysis, and to investigate how these affect the choice of options.

2. One of the approaches to investigate these uncertainties is Monte Carlo analysis. This is a risk modelling technique that presents a range of possible outcomes, the probabilised distribution of values within that range, and the expected value of the collective impact of various risks. It is particularly useful when there are many input variables with significant uncertainties.

3. The analysis here has used Monte Carlo analysis with the @RISK model to investigate the main uncertainties for two measures:

   - Measure R. (E (incentives for LEV) + N (Shipping) + C2 (Euro Standard)).
   - Measure B. Vehicle Emission Reduction Scenarios (more intensive scenario).

4. The analysis has focused on the key parameters that make a significant difference to the values, focusing on the long-term effects that dominate the economic analysis. The main uncertainties considered in detail are in the relative risk coefficient for chronic mortality (life years saved) from PM pollution, the lag phase involved, and the valuation of a life year lost. Analysis has also investigated uncertainty in cost estimates, based on the literature on ex ante and ex post out-turns (using a range from 50% to 120% of ex ante estimates). The Monte Carlo analysis was performed for the two measures in an 8-way sensitivity analysis considering different scenarios on lag phase and the inclusion of climate effects and possible impacts of pollution on morbidity.

5. Summary results for the two measures considered in the Monte Carlo analysis are shown below[2]. The 'lowest' figures are based on the scenario of a 40 year lag between release and effect and may be considered artificially low. The best estimate assumes that the lag varies from 0 to 40 years, but with 30% of impact occurring within 5 years of exposure.

		Benefit (£ billion) (best estimate)	Net benefit (benefit – cost) (£ billion) (best estimate)	Probability of net benefit (single point costs)	Probability of net benefit (50% to 120% for costs)
R	Lowest	–0.95	–0.17	47%	54%
	Highest	–3.2	–2.5	85%	94%
	Best estimate	**–2.0**	**–1.2**	**75%**	**83%**
B	Lowest	–0.71	+0.29	26%	32%
	Highest	–2.0	–1.0	70%	74%
	Best estimate	**–1.3**	**–0.34**	**55%**	**60%**

[1] This work was undertaken by Mike Holland and Paul Watkiss (EMRC and Paul Watkiss Associates, http://www.paulwatkiss.co.uk)

[2] Best estimates in the table are based on the scenario 5 that assumes that 30% of the health benefits occur in the first five years.

6. Total benefits for Measure R are estimated at £2 billion for the best estimate with variable lag included (consistent with the latest COMEAP/QUARK statements and reflected in the 'highest' as well as the 'best estimate' results). Net benefits (once costs have been subtracted) are £1.2 billion per year. The resulting probability of benefits exceeding costs for measure R is between 75% and 83%. With additional morbidity effects (from the EC's CAFE assessment) the probability that benefits exceed costs rises to 85% to 94%.

7. An equivalent analysis with Measure B shows reduced total and net benefits (£1.3 billion and £340 million per year respectively) and a lower probability – 56% to 61% – that benefits exceed costs according to the best estimate. Adding in further morbidity benefits raises the probability to between 70 and 74%.

8. Having quantified the probability of deriving a net benefit, it is necessary to ask how large the probability needs to be to justify action. Some may accept anything greater than 50%; some may accept a lower figure (perhaps in recognition of the omitted benefits); others may require a higher figure (perhaps through concern over effects on industry). It is not, however, a scientific decision. Some further information on this is provided in Appendix 1 section 2 of the report, drawing on the position adopted in reports of the Intergovernmental Panel on Climate Change (IPCC).

9. Based on the IPCC approach, the probability of benefits exceeding costs for measure R are classified as 'likely' (>66%), whilst for measure B they are 'more likely than not (>50%).

A7.2 Introduction

10. An expected central value is useful for understanding the impact of risk between different options. But as the HM Treasury Green Book identifies, *however well risks are identified and analysed, the future is inherently uncertain. So it is also essential to consider how future uncertainties can affect the choice between options.*

11. One of the tools for investigating these uncertainties is Monte Carlo analysis. This approach is specifically identified in the Green Book, which describes it as *risk modelling technique that presents both the range, as well as the expected value, of the collective impact of various risks. It is useful when there are many variables with significant uncertainties*.

12. A Monte Carlo analysis has been undertaken to investigate a number of measures from the Air Quality Strategy review. The uncertainty analysis assesses two measures:

- **Measure R – (E (incentives for LEV) + N (Shipping) + C2 (Euro Standard)).** Long-term. This is a new combined measure comprising the proposed measures being taken forward by the new Air Quality Strategy. This is a combination of Measure C2 (programme of incentives for the early uptake of Euro 5/V/VI standards), Measure E (incentives to increase the uptake of LEVs) and Measure N aimed at reducing emissions from shipping.

- **Measure B – Vehicle Emission Reduction Scenarios (more intensive scenario).** Long-term. This is a version of the European Regulations on Light Duty and Heavy Duty Vehicles (Euro standards 5/6/VI), expected to be introduced progressively from 2010 onwards. Version B is a more intensive emissions reduction scenario, requiring higher percentage reductions in NO_X and PM from vehicles)[3].

13. Monte Carlo analysis has been applied using the @RISK model. This permits investigation of uncertainties through the definition of probability distributions for key parameters in terms of (e.g.) mean values and the spread of values around them, and subsequent sampling across these distributions.

14. The study is focusing on key parameters that make most difference to the values. Following discussion with IGCB, the following key parameters are investigated within the Monte Carlo modelling.

1. Relative Risk Coefficient for chronic mortality (life years saved) from PM pollution.
2. Valuation of mortality.

These are modelled assuming a distribution for each, and input into @RISK.

3. Lag phase for chronic mortality.

This is modelled using discrete choices for no lag, and 40 year lag, but also with a probability distribution function derived based on the COMEAP/QUARK text, i.e. reflecting that the benefits resulting for a reduction in air pollution are likely to occur significantly earlier than 40 years – a noteworthy proportion in the first 5 years. The no lag and 40 year lag scenarios represent extremes and preference is given here to the scenarios involving a lag distributed over time, and with 30% or 50% occurring in the first 5 years.

4. Uncertainty in cost estimates.

A tendency for costs to be overestimated has often been noted, though the opposite may sometimes be the case. Here, a range of 0.5 × best estimate to 1.2 × best estimate has been assumed, with a triangular distribution.

Some additional sensitivity analysis has been carried out:

5. Using CAFE morbidity functions. COMEAP are currently discussing their position with respect to morbidity assessment. The function set here is the same as that adopted following recommendation by WHO for the cost-benefit analysis of the Clean Air For Europe (CAFE) Programme.

6. Using estimated benefits of CO_2 abatement (social costs of carbon) as estimated by the IGCB.

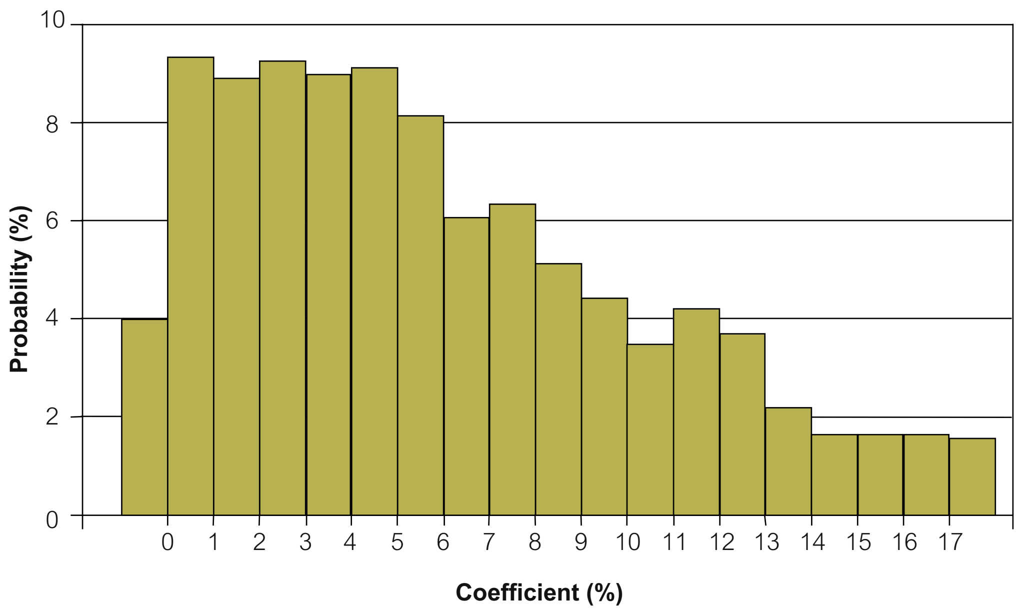
[3] Two other versions considered in the main IGCB analysis are a less intensive emission reductions scenario (existing Measure A), and a version that reflects the most recent proposals for the new standard (new Measure A2).

A7.2.1 Chronic Mortality Relative Risk Coefficient

15. A number of possible distributions were considered for the relative risk coefficient, based on the work undertaken by COMEAP. Through expert meetings and analysis, the COMEAP Members produced a distribution of the relative risk coefficients (to be published in the forthcoming QUARK report). A number of different approaches were considered. The Monte Carlo analysis here has matched the probability distribution function of COMEAP Members expert judgement (see below) to a fitted @RISK distribution[4]. The original COMEAP function and the best fitted distributions are shown below.

Figure 7.1

COMEAP member distribution of relative risk coefficient (QUARK)[5]



16. The first bar represents the probability of the coefficient being 0 or less (no adverse effect) and the last barof it being more than 17%.

17. The Figure above shows, for possible values of the coefficient in the range 0 to 17%, the average (arithmetic mean) probability assigned by Members. For example, on average a 4% probability was assigned to the coefficient being zero or less (left-most bar), about a 9% probability was assigned to the coefficient being above 0 but not more than 1, i.e. including 1 (second bar), and so on.

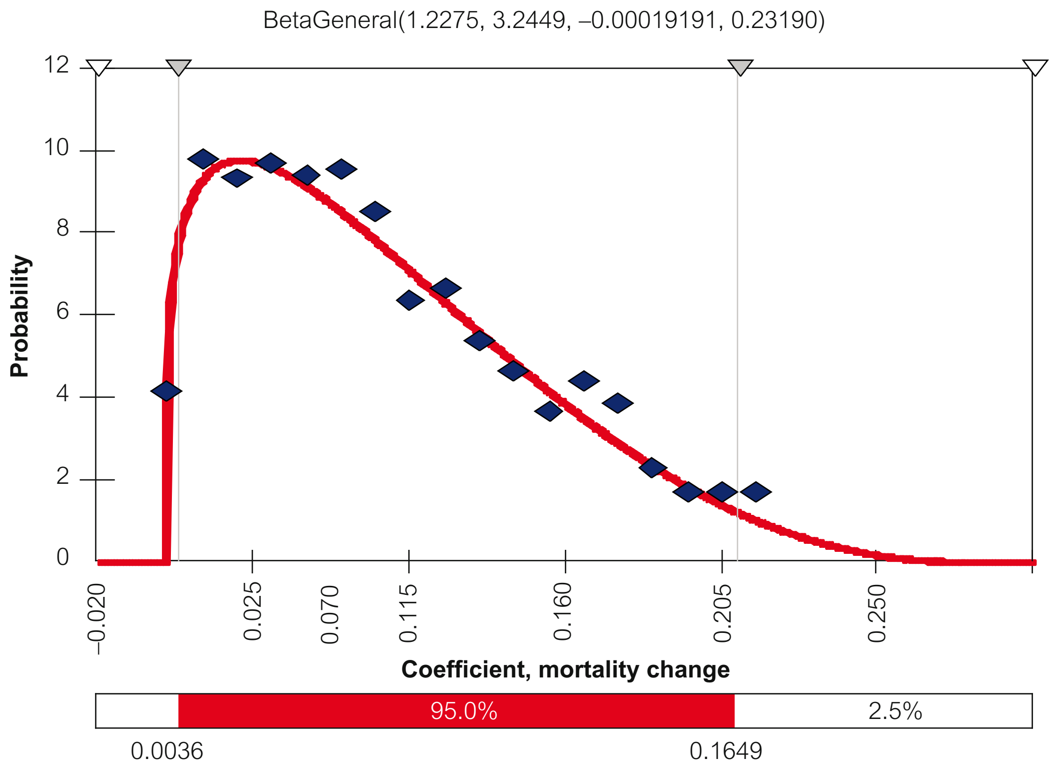
18. These data were entered to @RISK, which found that a Beta (Generalised) function gave the best fit (Figure 7.2). Appendix 2 shows alternative distributions (in descending order of best fit).

[4] The COMEAP members also produced some estimates for sensitivity analysis from this distribution with values of 1% and 12% as 'typically low' and 'typically high' points.

[5] QUARK report (Department of Health, 2007)

Figure 7.2

Best fit @RISK approximation (red line) for COMEAP member distribution (blue diamonds), following the Beta Generalised distribution. Again, see Appendix 1 section 2 for information on the interpretation of probability diagrams



19. Summary statistics for this Beta Generalised distribution are as follows:

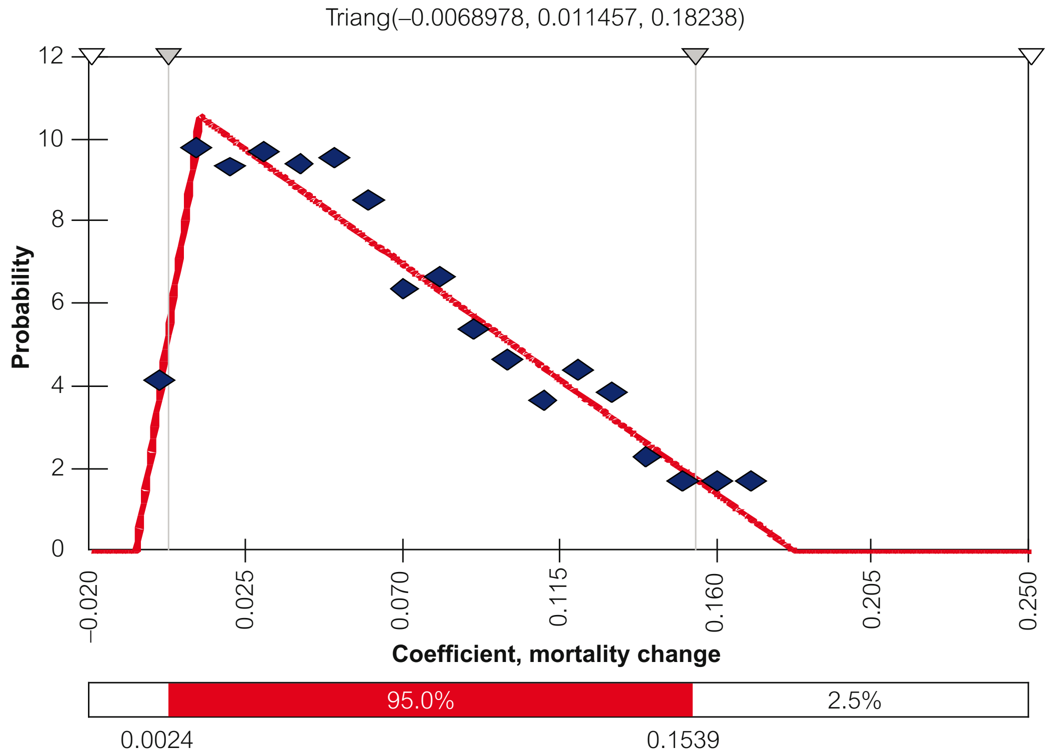
- α1 (continuous shape parameter) 1.23
- α2 (continuous shape parameter) 3.24
- Minimum value –0.00019 (0.06% of values fall below zero)
- Maximum value 0.23
- Mean 0.064 (i.e. 6.4%)

20. Further information on the Beta (Generalised) function is given in Appendix 1.

21. Unfortunately, there are problems with this distribution. First, it extends below zero, though as this affects less than 0.1% of values its effect on the probability of achieving any particular outcome is negligible. Second, values extend up to 0.23, when COMEAP explicitly went only as far as 17%. As only 1.9% of values are >17% this again has a limited effect on the results. Third, it gives an average output of 6.4% rather than the 6% considered as best estimate by COMEAP. Statistically, the second best fit was a simple triangular distribution (Figure 7.3).

Figure 7.3

Second best fit @RISK approximation (red line) for COMEAP member distribution (blue diamonds), following the triangular distribution



22. Summary statistics for this distribution are as follows:

- Minimum value –0.0069 (1.3% of values fall below zero)
- Maximum value 0.18
- Most likely value 0.0115 (i.e. 1.15%)
- Mean value 0.0623 (i.e. 6.23%)

23. This distribution has two advantages and one disadvantage compared to that shown in Figure 7.2. The advantages are that the mean value (6.23%) is closer to COMEAP's best estimate of 6%, and that the maximum value agrees with the upper end of the range considered by COMEAP. The disadvantage is that more values fall below zero (1.3% rather than 0.06%). This can be corrected by truncating the distribution at zero, though this increases the mean to 6.38%. IGCB Members expressed a preference for the triangular distribution and so this has been used in the analysis that follows, truncating at zero to give the following summary statistics:

- Minimum value 0
- Maximum value 0.18
- Most likely value 0.0115 (i.e. 1.15%)
- Mean value 0.0638 (i.e. 6.38%)

A7.2.2 Lag Phases

24. There is no agreement from COMEAP on the probability of the lag phase, beyond the current range of between 0 and 40 years. The analysis has therefore combined the truncated triangular distribution with two discrete choices of no lag, and a 40 year lag. There is, however, some draft text from DoH/COMEAP on the likelihood of when impacts might occur:

25. *The time series studies… show (assuming causality) that some benefit is more-or-less immediate. We know however that the time series studies capture only a small proportion of the overall impact on mortality implied by the cohort studies. Of greater relevance, therefore, are the studies of policy interventions in Dublin (Clancy et al, 2002) and in Hong Kong (Hedley et al, 2002). In both cities, reductions in air pollution were followed by mortality benefits in the subsequent five-year period. This suggests a reduction in pollution-related risks of mortality in the years shortly after the pollution is reduced. We do not know what further reductions in risks may have occurred after five years, or indeed may yet occur.*

26. *Having done a rapid examination of the rate at which the deaths fell in the Dublin study, we feel that though in principle it might take as long as 40 years for all of the mortality benefits to be achieved, in practice a bulk of the benefits are likely to occur significantly earlier than that, including a noteworthy proportion in the 1st five years. We believe this is particularly likely in the case of effects on the cardio-respiratory system but not in the case of lung cancer. As the cardiovascular effects dominate all-cause mortality we consider that the cessation lag for all-cause mortality is, on average, also substantially less than 40 years.*

27. *Thus, although the evidence is limited, our judgment tends towards a noteworthy proportion of the whole effect occurring in the years soon after pollution reduction rather than later.*

28. Therefore, as an alternative to the options of 0 or 40 year lag, probability distributions have been generated to reflect the text above. To do this it is assumed that:

- Some benefits occur immediately (i.e. acute effects following pollution events) and so the distribution should not be set to zero on the vertical axis.
- The absolute range is from an immediate effect to a maximum of 40 years.
- The distribution is strongly skewed to give two alternative functions:
  - 30% of benefits in the first five years
  - 50% of benefits in the first five years[6].

30. A Pearson distribution has been used, simply because it provided a reasonable fit against the criteria just defined (Figure 7.4). These scenarios underpin calculation of 'best estimates' as cited in the Executive Summary.

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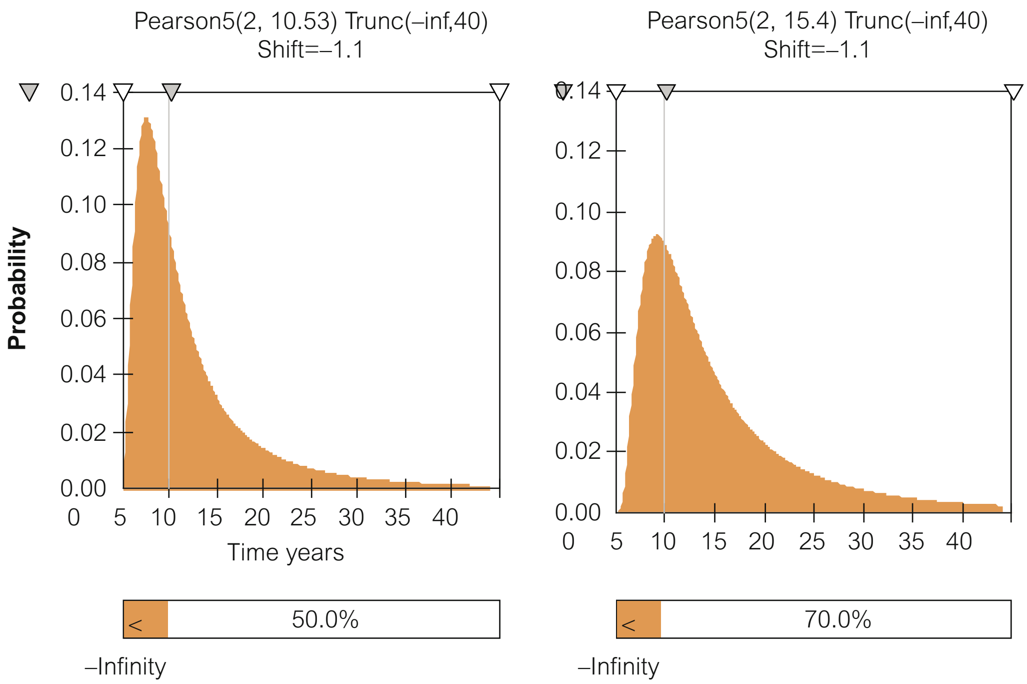
[6] The USEPA has considered a multi-step lag phase, which assumes 30% of the effect of reduced pollution on deaths rates occurs immediately (year1); 50% of the effect is distributed over years 2-5; and the remaining 20% is distributed over years 6-20. This therefore gives 80% of effects in the first five years – a higher amount than assumed here.

Figure 7.4

Lag phase distribution, with 50% and 30% of impact occurring in first 5 years
(left hand and right hand figures respectively)

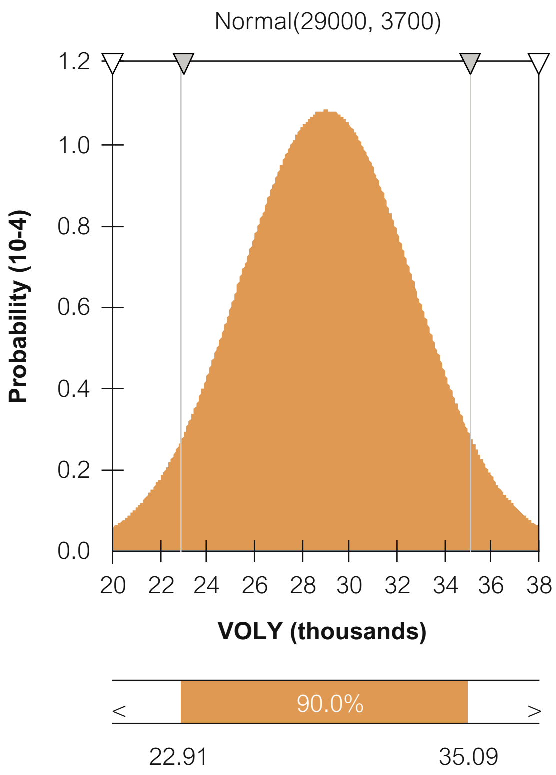


A7.2.3 Valuation

31. Uncertainty around valuation is based on the underlying Chilton study (2004). This gives a best estimate of £27,630, with a 95% confidence interval of £20,690 to £34,440. The central estimate and CI have been updated for use in the AQSR analysis to £29,000 with 95% confidence interval of £21,700 – £36,200.

Figure 7.5

VOLY distribution



A7.3.1 Analysis Approach

32. The analysis starts with the population weighted mean PM exposure (UK- grav) as estimated in the NETCEN modelling of the AQSR measures. The updated values (with new secondary particulate formation rates – see below) are used.

33. No uncertainty analysis is applied to emissions, concentration modelling, or population projections, though some testing with these parameters would be possible (and could be important, e.g. in relation to model predictions, meteorological year, assumptions over PM_{10} vs. $PM_{2.5}$, population growth, etc.). Further discussion of uncertainty across the full impact-pathway is considered in Appendix 3.

34. The analysis takes the population weighted values and estimates the monetary benefits, by applying the relevant distributions to relative risk coefficient and valuation, for discrete lag phase assumptions, but also with the probability distribution for lag period. Monte Carlo sampling is applied with 10,000 iterations for each model run.

A7.3.2 Presentation of Results

35. A key issue for this work has been to consider how uncertainty information is presented. The work here has reviewed previous examples (through case studies and literature review) of presenting uncertainty information to policy makers. This has identified two key studies which have influenced our presentation of benefits.

36. First, the uncertainty work as part of the CAFE cost benefit analysis (Holland et al[7]). This advanced the use of Monte Carlo analysis and probability distribution functions for presenting uncertainty for air quality policy. It also advocated the comparison of cost and benefits through the simple plotting of the probability of benefits exceeding costs (this was found to be the best way to present the uncertainty analysis in a single graph)

- Second, work in the US (Krupnick et al)[8] on presenting uncertainty to policy makers in regulatory impact analyses in the US. This study looked at different ways of presenting uncertainty to real policy makers using hypothetical case studies. A key observation from this work, which is very relevant here, is that:

*'better and more complete information (*on uncertainty*) does not necessarily lead to better policies. Complex information can confound rather than enlighten or can paralyze the decision-making process. Improvements in capturing uncertainty must be matched by improvements in communication'.*

37. The US work also found that decisions are often influenced simply by the manner in which a policy (uncertainty) is presented. The study found that graphical techniques worked well for communicating uncertainty, especially the box and whisker plot, probability distribution functions, and cumulative distribution functions, in allowing the audience to accurately extract quantitative information. Area and volume presentations were found to be misleading and caused viewers to underestimate large magnitudes. It also looked at ways to convey uncertain variables, finding tornado graphs (a graph showing the contribution of each variable to overall uncertainty) very useful.

A7.3.3 Sensitivity Analysis and Omitted Areas

38. The Appendix also highlights a number of areas which have not been assessed, but that are potentially important to the uncertainty present in the analysis. These might best be captured through sensitivity analysis. These include:

- Secondary organic aerosols associated with VOC emissions. Analysis of this omitted category has been shown in sensitivity analysis to be potentially important. This could affect some of the priorities in the ranking of different measures, especially where they include VOC control.
- Potential toxicity variations across the particulate mixture. There is growing evidence that different elements of the particulate mixture have different toxicity (the difference between primary, secondary sulphates, secondary nitrate particles). The evidence seems to be indicating that primary particulate matter is of most concern.
- The consideration of other morbidity health endpoints, for example comparing the difference between the CAFE HIA set and the COMEAP HIA set.
- The consideration of benefits for ecosystems.

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[7] Mike Holland, Fintan Hurley, Alistair Hunt, Paul Watkiss (2005). Volume 3: Uncertainty in the CAFE CBA: Methods and First Analysis. Service Contract for Carrying out Cost-Benefit Analysis of Air Quality Related Issues, in particular in the Clean Air for Europe (CAFE) Programme. http://europa.eu.int/comm/environment/air/cafe/activities/cba.htm

[8] Resources for the Future (2006). Not A Sure Thing: Making Regulatory Choices Under Uncertainty. Alan Krupnick, Richard Morgenstern, Michael Batz, Peter Nelson, Dallas Burtraw, JhihShyang Shih, and Michael McWilliams. February 2006

39. As part of the sensitivity analysis carried out below, the CAFE morbidity response and valuation function set has been included[9], as additional health endpoints are part of the current discussion in COMEAP. This brings in a number of additional health endpoints,

- Chronic Bronchitis (adults)
- Restricted Activity Days (adults)
- Respiratory medication use (children)
- Respiratory medication use (adults)
- Lower respiratory symptom (LRS) days (children)
- Lower respiratory symptom (LRS) days among adults

40. These are brought into the analysis by defining the sensitive fraction of the population for each effect, and multiplying by population-weighted average exposure, response factors and valuation factors.

A7.4 Benefit Results

41. Here, the benefits of Measures R and B are considered. This brings together three discrete measures:

- Measure C2: Programme of incentives for early uptake of Euro 5/V/VI standards
- Measure E: Incentive to increase penetration of low emission vehicles
- Measure N: Shipping: the global shipping fleet is required to use 1% sulphur fuel and reduce NO_X emissions by 25%.

42. Note benefits are presented as negative values (i.e. the opposite of costs).

Table 7.1: IGCB Benefit results (final revised) for Long-Term YOLL – with 50% formation of secondary particulates

	YOLL (000) 6%no lag – lag	Valuation Annual Present Value (PV) £ M
Measure R*	–2,020 to –3,805	–886 to –2,039
of which 100 year exposure	–1,962 to –3,745	–831 to –1,952
Measure B	–1,581 to –3,017	–669 to –1,571

* long-term effect. Note an additional reduction in exposure for 20 years is also part of this measure (–58 to –61 YOLL (000). This is not an acute effect e.g. deaths brought forward. It is the long-term consequence (over 100 years) of an additional exposure that lasts 20 years. With these included the total YOLL rise to –2,020 to –3,805, but this decrease in YOLL is not included in the long-term assessment below as they cannot be directly added within the same distribution (they must be assessed in a separate distribution, because of the different effects per YOLL when expressed in monetary terms due to uplift and discounting). These additional benefits increase the overall valuation Annual PV for YOLL to £–886 to –2,039.

[9] Hurley, F., Cowie, H., Hunt, A., Holland, M., Miller, B., Pye, S., Watkiss, P. (2005) Methodology for the Cost-Benefit analysis for CAFE: Volume 2: Health Impact Assessment. http://cafe-cba.aeat.com/files/CAFE%20CBA%20Methodology%20Final%20Volume%202%20v1h.pd

43. The values above only give estimates for chronic mortality . There are other benefits quantified in the IGCB analysis (for morbidity and buildings, crops and materials) – these are estimated at 1 to 5 million, but as these are so small compared to chronic mortality they are not considered further.

44. However, there are also additional carbon benefits, which are potentially important and these have been estimated at a benefit of £36 million (annual PV) for measure R and an impact (increase) of £86 million for measure B.

45. As noted above, there are two values for YOLL improvements for measure R, due to an additional reduction in exposure in the first 20 years of the measure over and above the 100 year exposure YOLL benefits (the total, and benefits due to 100 year exposure only are quoted separately in Table 7.1 – see table footnote above). These additional YOLL improvements from 20 year exposure cannot be added to the 100 year exposure directly: this is because they have a different distribution of monetary benefits due to the effect of the uplift and the discount rate (and thus they lead to a different level of benefits, per YOLL). They must therefore be added as a separate impact into the Monte Carlo analysis. The total benefits in physical and monetary terms are summarised below.

Table 7.2: IGCB Benefit and Input used here

	Long-Term Benefits (YOLL) 6% Annual PV £ M	Other Benefits Annual PV £ M	Total Benefits Annual PV £ M
Measure R (IGCB) *	–886 to –2,039*	–4 to +14 other –36 carbon	–918 to 2,089
Used here	–831 to –1,952 (excludes 20 year reduction in exposure*)	–55 to –87 (YOLL 20 yr) –36 (carbon)	–922 to 2,075
Measure B (IGCB)#	–669 to –1,571	–12 to +(12) other (+86) Carbon	–571 to –1,497
Used here	–669 to –1,571	+ (86)	–583 to –1,485

* includes YOLL benefits from an additional 20 year reduction in exposure.

note with other benefits from crops and materials and other health effects including from ozone, the total changes to –606 to –1,532, as reported in the main document

46. The costs of the measures are summarised below. The range around costs is extremely small, and for practical purposes is a point estimate. Therefore in the analysis below, the higher value is used as a single point estimate. Note costs are presented with a positive value.

Table 7.3: IGCB – Costs of implementing the Measures

	Valuation Annual PV of Cost £ Million
Measure R	+878 to + 885
Measure B	+983 to + 1,003

47. The net benefits of the measures are summarised below.

Table 7.4: IGCB – Annual costs and benefits of implementing the Measures

	Annual PV of Benefit £ Million	Annual PV of Cost £ Million	Annual PV Cost £ Million
Measure R in IGCB	-918 to 2,089	+878 to +885	–33 to –1,211
Measure R here	-922 to 2,075	+885	–37 to –1,190
Measure B in IGCB	–571 to –1,497	+983 to +1,003	+(432) to –514
Measure B here	–583 to –1,485	+1003	+(420) to –482

A7.4.1 Benefits of Measure R

48. The distribution of benefits for measure R are shown below. Benefits are presented with a negative value. The distribution of benefits is shown for the following scenarios:

1) COMEAP member distribution approximated using a truncated triangular distribution, plus valuation distribution, 40 year lag, including estimated short term YOLL benefits

2) As [1], with lag distributed over 40 years and 30% coming in the first 5 years.

3) As [1], with lag distributed over 40 years and 50% coming in the first 5 years.

4) As [1], for a 0 year lag

5) As [2], plus climate benefits

6) As [2], plus climate benefits plus CAFE morbidity. CAFE valuations were weighted by ratio of the best estimate for YOLL used here and the best estimate of YOLL used in CAFE, reflecting observed variation between European countries in which valuation studies have been performed. Uncertainties in the CAFE morbidity quantification are fed through to the Monte Carlo analysis.

7) As [3], plus climate benefits

8) As [3], plus climate benefits plus CAFE morbidity

49. No account is taken of uncertainty in climate benefits for scenarios 5 to 8, though their contribution to total benefits is small, at around 2%. Although uncertainties in climate benefits are certainly large they are therefore unlikely to influence conclusions drawn to a significant degree. Distributions are plotted below for scenarios 5 and 7, as these are considered to best reflect current guidance from COMEAP and IGCB. Distributions are provided in Appendix 4 for the other scenarios listed, whilst summary results for all are given in Table 7.5 below.

Figure 7.6

Annualised benefits of Measure R, lag for mortality impacts distributed over 40 years with 30% coming in the first 5 years with climate benefits added. Annual present value £ billion with 95% confidence interval shown

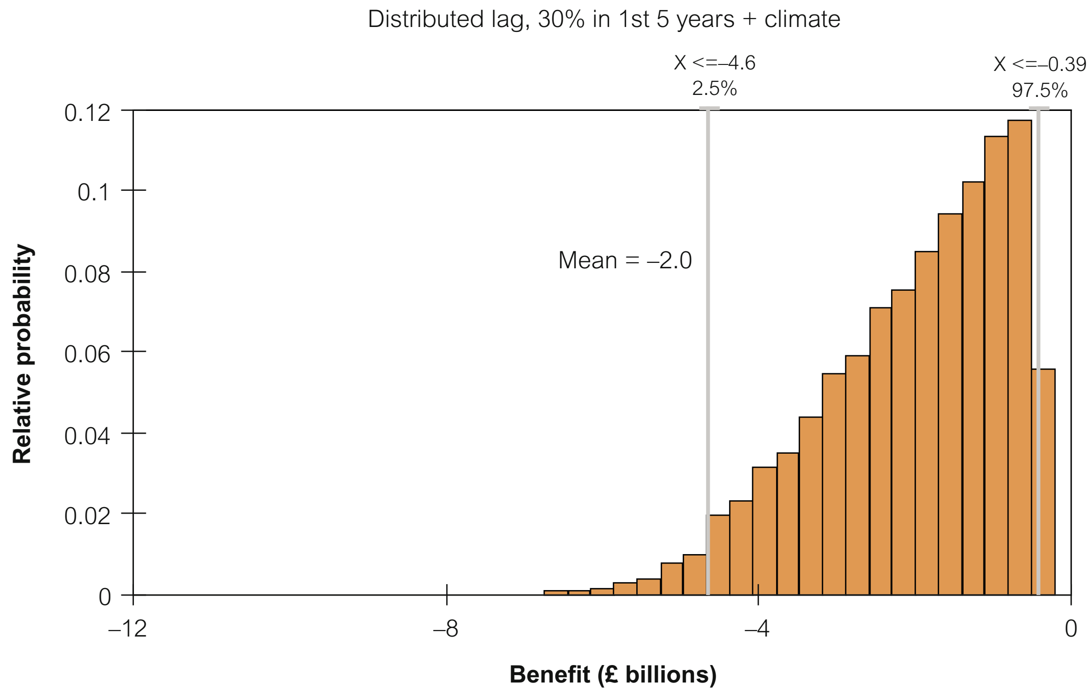


Figure 7.7

Annualised benefits of Measure R, lag for mortality impacts distributed over 40 years with 50% coming in the first 5 years with climate benefits added. Annual present value £ billion with 95% confidence interval shown

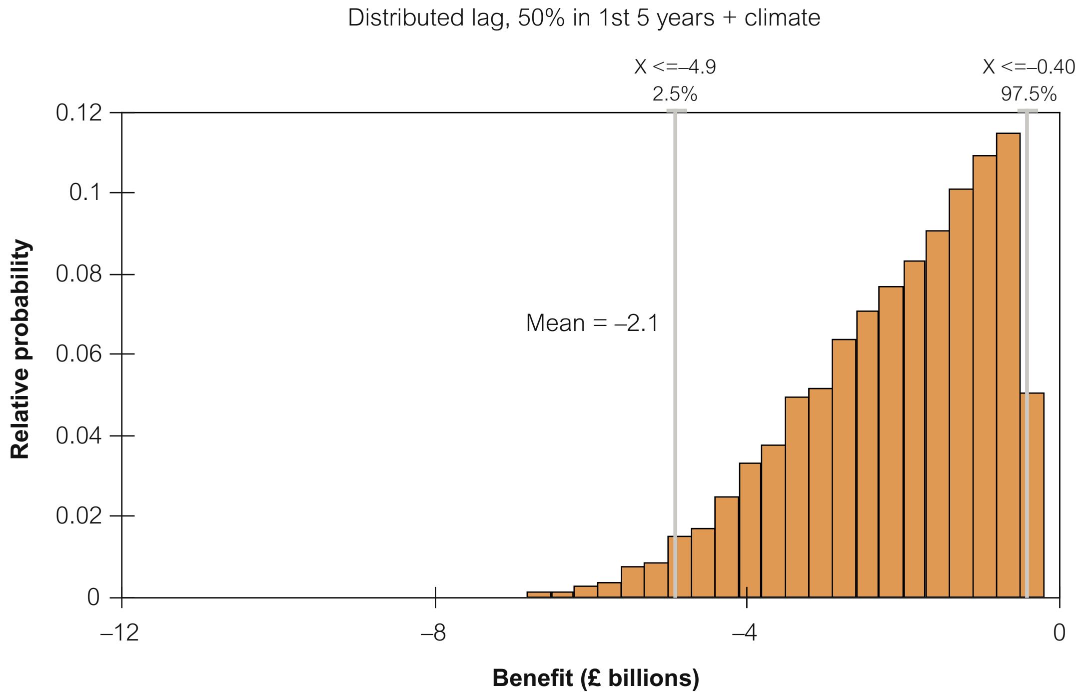


Table 7.5: Best estimates of total benefits for Measure R. Negative (–) figures show benefits

	Description of scenario	Benefit (£billions)	95% confidence interval
	IGCB analysis (no Monte Carlo) – long-term exposure (100 year)	–0.83 to –1.95	
	IGCB analysis (no Monte Carlo) – long-term exposure (20 + 100) + short-term health + climate	–0.92 to –2.09	
1	Lag = 40 years	–0.95	–0.17 to –2.2
2	Variable lag, 30% in 5 years	–1.9	–0.33 to –4.6
3	Variable lag, 50% in 5 years	–2.0	–0.34 to –4.8
4	Lag = 0 years	–2.1	–0.30 to –5.2
5	Variable lag, 30% in 5 years + climate	–2.0	–0.39 to –4.6
6	Variable lag, 30% in 5 years + CAFE morbidity + climate	–3.2	–0.56 to –7.5
7	Variable lag, 50% in 5 years + climate	–2.1	–0.40 to –4.9
8	Variable lag, 50% in 5 years + CAFE morbidity + climate	–3.2	–0.57 to –7.9

50. The following are noted from these results:

1. The distribution is strongly skewed right (in this case, towards 0 as benefits are shown as negative numbers) in all cases

2. Estimates of mean benefits vary by a factor >3 between the different scenarios investigated.

3. The benefits for scenario 1 (40 year lag) are 55% lower than for scenario 4 (0 year lag). However, there is only a small difference between scenario 4 and scenarios 2 and 3 (variable lags).

A7.4.2 Comparison of costs and benefits for Measure R

51. The best estimates of costs of Measure R have been estimated at £878 to £885 million, as an annual PV. These are compared with annualised benefits (to the extent that they are quantified, and excluding various effects that are not such as on ecosystems, cultural heritage, etc.).

52. The range in costs does not capture the extent of variability seen between ex-ante and ex-post estimates of costs. These are likely to have a potentially large effect in the actual policy out-turn and the actual net benefits, and a sensitivity has also been investigated here on this issue: a range of 0.5 to 1.2 times the mid point of the cost range has been applied, reflecting the limits adopted in the CAFE analysis for EC DG Environment. This is entered as a triangular distribution, with most likely value corresponding to the mid point of the cost range.

53. Results are shown for scenarios 5 and 7 from the list above in Figure 7.8 and Figure 7.9, and in Appendix 4 for all other scenarios. Summary results for all are shown in Table 7.6.

Figure 7.8

Annualised net benefits of Measure R, lag for mortality impacts distributed over 40 years with 30% coming in the first 5 years with climate benefits added. Annual present value £ billion

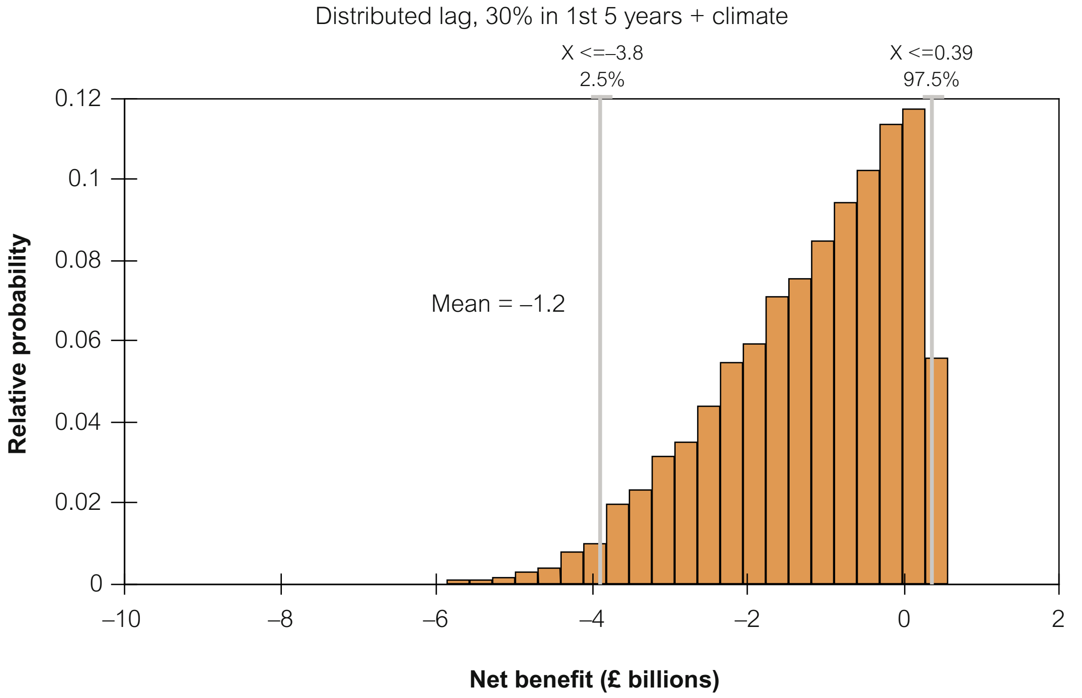


Figure 7.9

Annualised net benefits of Measure R, lag for mortality impacts distributed over 40 years with 50% coming in the first 5 years with climate benefits added. Annual present value £ billion

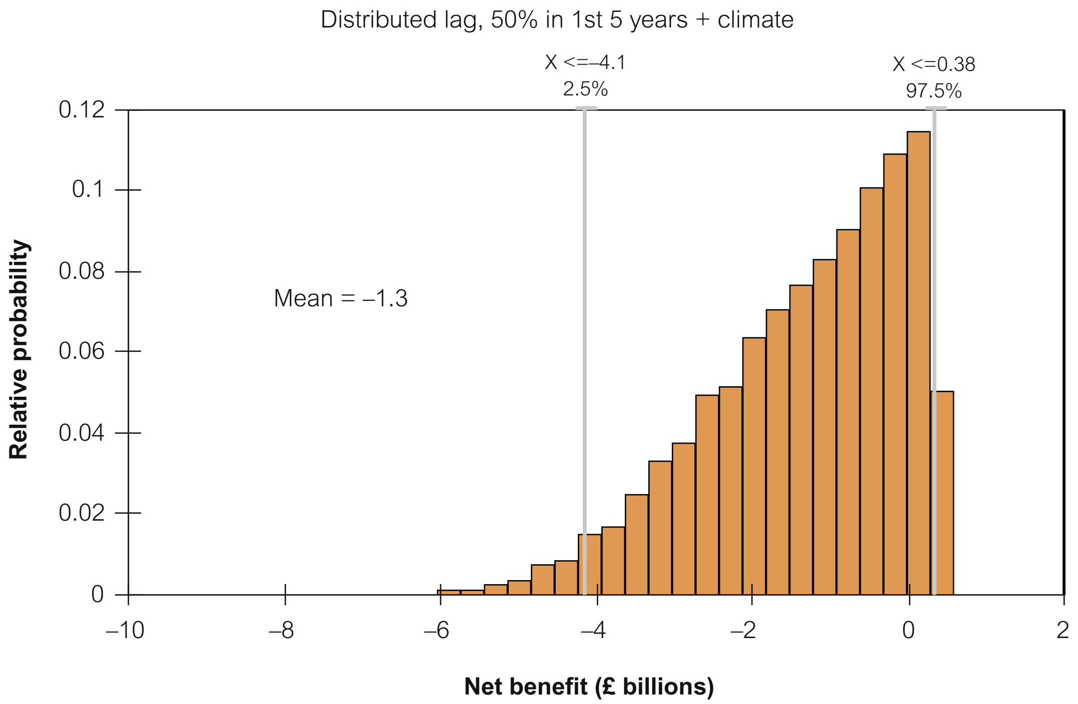


Table 7.6: Best estimates of net benefits (benefit-cost) from the Monte Carlo analysis for Measure R. Negative (–) figures show (net) benefits, positive (+) figures show (net) costs.

	Description of scenario	Net benefit (£billions)	95% confidence interval
	IGCB analysis (no Monte Carlo) – long-term exposure (20 + 100) + short-term health + climate	–0.03 to –1.21	
1	Lag = 40 years	–0.17	+0.61 to –1.5
2	Variable lag, 30% in 5 years	–1.1	+0.45 to –3.8
3	Variable lag, 50% in 5 years	–1.2	+0.44 to –4.0
4	Lag = 0 years	–1.4	+0.48 to –4.4
5	Variable lag, 30% in 5 years + climate	–1.2	+0.39 to –3.8
6	Variable lag, 30% in 5 years + CAFE morbidity + climate	–2.4	+0.22 to –6.7
7	Variable lag, 50% in 5 years + climate	–1.3	+0.38 to –4.1
8	Variable lag, 50% in 5 years + CAFE morbidity + climate	–2.5	+0.21 to -7.0

54. All runs show significant net benefits for mean values (shown as a negative in the table), though 95% confidence intervals cross into net costs at their lower end. The probability of benefits exceeding costs is summarised below.

Table 7.7: Probability of net benefit for Measure R under different assumptions, against single point estimates of costs and a range drawn from evidence of ex-ante/ex-post comparison.

		Probability of net benefit	
	Description of scenario	above single point costs	above costs (with range 50% to 120% for costs)
1	Lag = 40 years	47%	54%
2	Variable lag, 30% in 5 years	74%	81%
3	Variable lag, 50% in 5 years	76%	82%
4	Lag = 0 years	78%	82%
5	Variable lag, 30% in 5 years + climate	75%	83%
6	Variable lag, 30% in 5 years + CAFE morbidity + climate	85%	93%
7	Variable lag, 50% in 5 years + climate	77%	84%
8	Variable lag, 50% in 5 years + CAFE morbidity + climate	85%	94%

55. What probability of gaining a net benefit is sufficient to justify taking action? Some may accept anything greater than 50%; some may accept a lower figure (perhaps in recognition of the omitted benefits) others may require a higher figure (perhaps through concern over effects on industry). It is not, however, a scientific decision. Some further information on this is provided in Appendix 1 section 2, drawing on the position recently adopted in reports of the Intergovernmental Panel on Climate Change (IPCC).

A7.4.3 Benefits of Measure B

56. The distribution of benefits for measure B are shown below. The distribution of benefits is shown for the same scenarios as for measure R:

1) COMEAP member distribution approximated using a truncated triangular distribution, plus valuation distribution, 40 year lag, including estimated short term YOLL benefits

2) As [1], with lag distributed over 40 years and 30% coming in the first 5 years.

3) As [1], with lag distributed over 40 years and 50% coming in the first 5 years.

4) As [1], for a 0 year lag

5) As [2], plus climate benefits

6) As [2], plus climate benefits plus CAFE morbidity. CAFE valuations were weighted by ratio of the best estimate for YOLL used here and the best estimate of YOLL used in CAFE, reflecting observed variation between European countries in which valuation studies have been performed. Uncertainties in the CAFE morbidity quantification are fed through to the Monte Carlo analysis

7) As [3], plus climate benefits

8) As [3], plus climate benefits plus CAFE morbidity

57. No account is taken of uncertainty in climate benefits for scenarios 5 to 8. Distributions are plotted for scenarios 5 and 7 in Figure 7.10 and Figure 7.11 as these are considered to best reflect current guidance from COMEAP and IGCB. Distributions are provided in Appendix 4 for the other scenarios listed, whilst summary results for all are given in Table 7.8 below.

Figure 7.10

Annualised benefits of Measure B, lag for mortality impacts distributed over 40 years with 30% coming in the first 5 years with climate benefits added. Annual present value £ billion

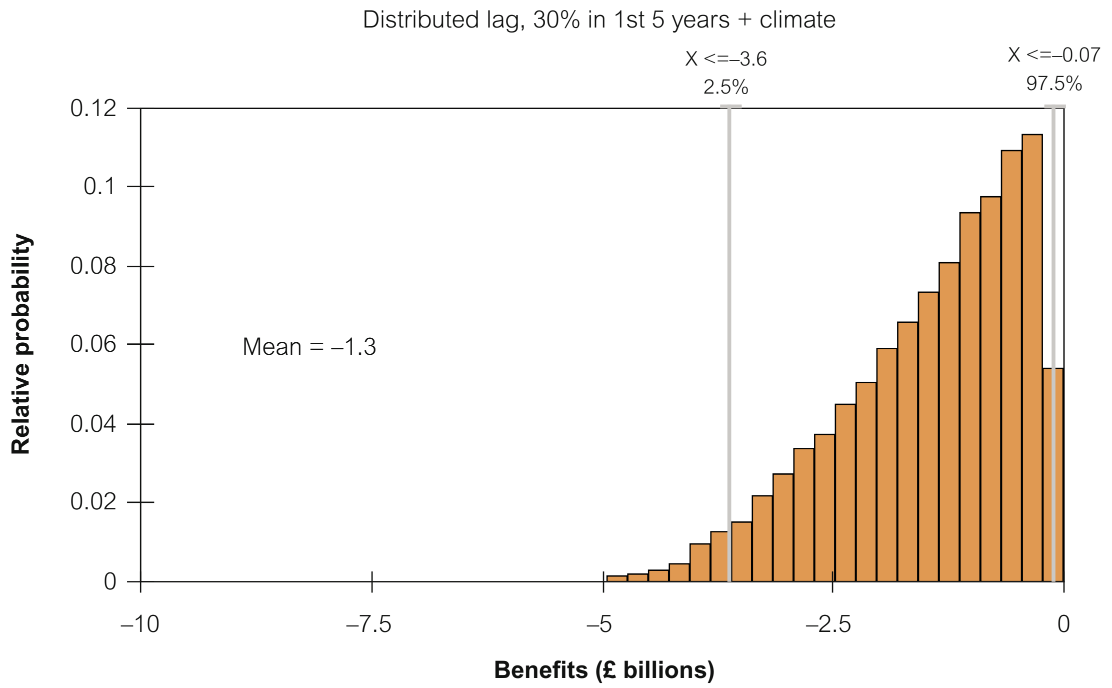
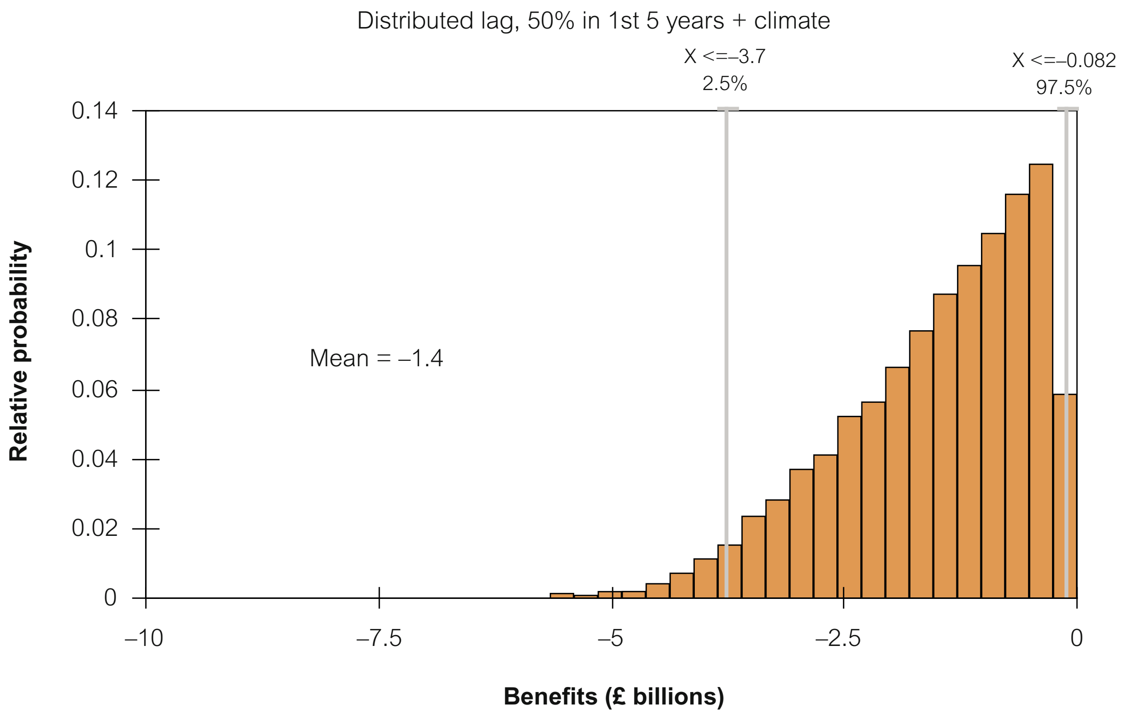


Figure 7.11

Annualised benefits of Measure B, lag for mortality impacts distributed over 40 years with 50% coming in the first 5 years with climate benefits added. Annual present value £ billion



58. The results are summarised below, showing the mean values (benefit) from the analysis.

Table 7.8: Best estimates of quantified benefits for Measure B. Negative (–) figures show benefits.

	Description of scenario	Benefit (£billions)	95% confidence interval
	IGCB analysis (no Monte Carlo) – long-term exposure	–0.67 to –1.57	
	IGCB analysis (no Monte Carlo) – long-term exposure with short-term health + climate	–0.57 to –1.50	
1	Lag = 40 years	–0.71	–0.08 to –1.8
2	Variable lag, 30% in 5 years	–1.4	–0.16 to –3.7
3	Variable lag, 50% in 5 years	–1.4	–0.17 to –3.8
4	Lag = 0 years	–1.7	–0.19 to –4.2
5	Variable lag, 30% in 5 years + climate	–1.3	–0.07 to –3.6
6	Variable lag, 30% in 5 years + CAFE morbidity + climate	–2.0	–0.14 to –5.2
7	Variable lag, 50% in 5 years + climate	–1.4	–0.08 to –3.7
8	Variable lag, 50% in 5 years + CAFE morbidity + climate	–2.0	–0.24 to –4.8

59. The following are also noted from these results:

1. The distribution is strongly skewed right (in this case, towards 0 as benefits are shown as negative numbers) in all cases
2. Estimates of mean benefits vary by a factor of 3 between the different scenarios investigated.
3. The benefits for scenario 1 (40 year lag) are 58% lower than for scenario 4 (0 year lag). However, there is only a 15% difference between scenario 4 and scenarios 2 and 3 (variable lags).

A7.4.4 Comparison of costs and benefits

60. The best estimates of costs of Measure B range from £983 to 1,003 million, as an annual PV. This range does not capture the full uncertainty in cost estimates, as shown in work comparing ex ante and ex post estimates. These uncertainties are sufficiently large to potentially affect conclusions drawn from the work. Accordingly in this analysis a range of 0.5 to 1.2 times the mid point of the cost range has been applied, reflecting the limits adopted in the CAFE analysis for EC DG Environment. Against these costs needs to be set the effects quantified here and others that are not accounted for. The latter include the benefits of reduced emissions on ecosystems, cultural heritage, etc. This range in costs does not capture the extent of variability seen between ex-ante and ex-post estimates of costs. These could potentially have a large effect in the actual policy out-turn and the actual net benefits.

Figure 7.12

Annualised net benefits of Measure B, lag for mortality impacts distributed over 40 years with 30% coming in the first 5 years with climate benefits added. Annual present value £ billion

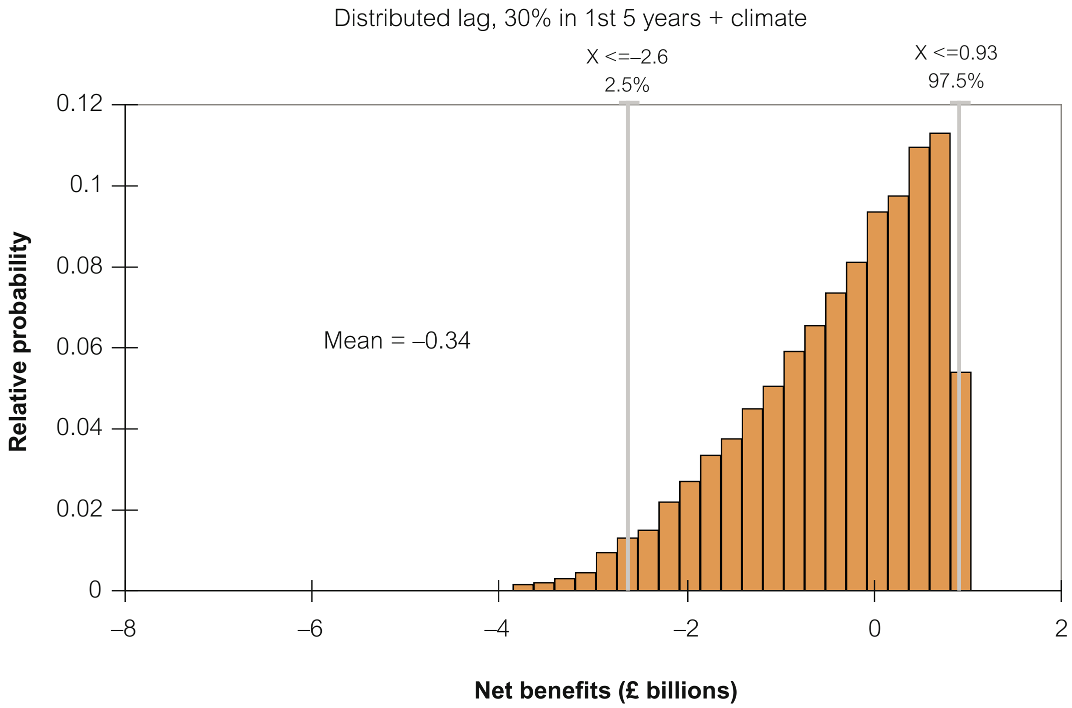
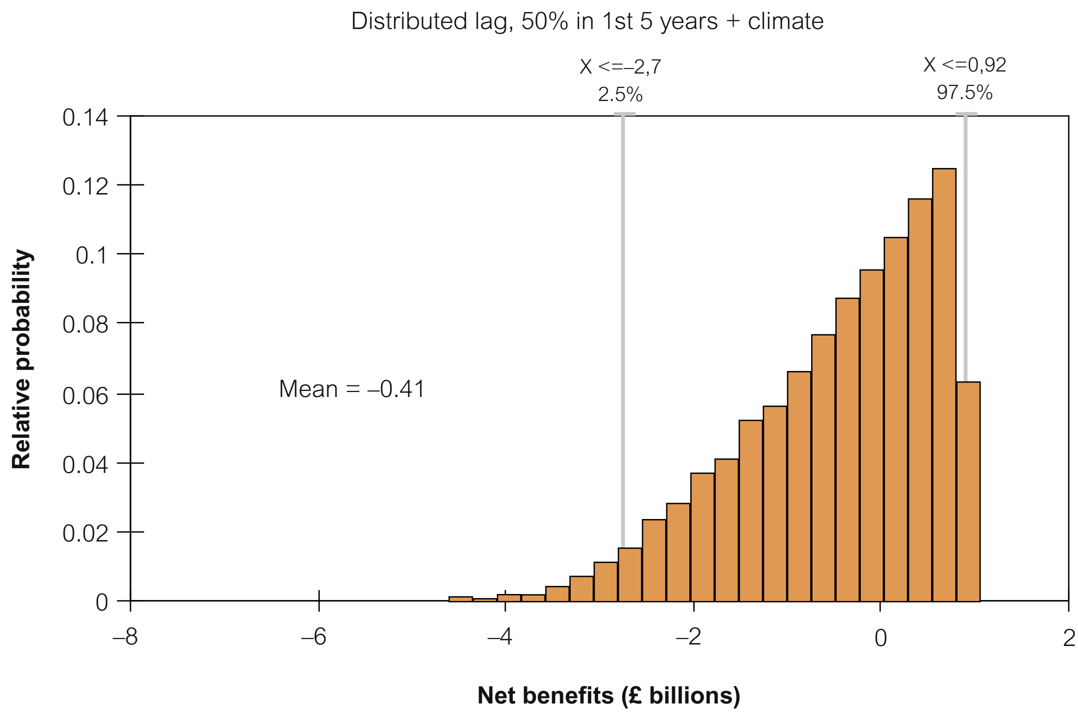


Figure 7.13

Annualised net benefits of Measure B, lag for mortality impacts distributed over 40 years with 50% coming in the first 5 years with climate benefits added. Annual present value £ billion



61. The summary of net benefits is included in the table below.

Table 7.9: Best estimates of total benefits and net benefits (benefit-cost) from the Monte Carlo analysis for Measure B. Negative (–) figures show (benefits, positive (+) figures show (net) costs.

	Description of scenario	Net benefit (£billions)	95% confidence interval
	IGCB analysis (no Monte Carlo) – long-term exposure with short-term health + climate	+0.43 to –0.51	
1	Lag = 40 years	+0.29	+0.92 to –0.77
2	Variable lag, 30% in 5 years	–0.42	+0.84 to –2.7
3	Variable lag, 50% in 5 years	–0.49	+0.84 to –2.8
4	Lag = 0 years	–0.66	+0.81 to –3.2
5	Variable lag, 30% in 5 years + climate	–0.34	+0.93 to –2.6
6	Variable lag, 30% in 5 years + CAFE morbidity + climate	–0.97	+0.86 to –4.2
7	Variable lag, 50% in 5 years + climate	–0.41	+0.92 to –2.7
8	Variable lag, 50% in 5 years + CAFE morbidity + climate	–1.0	+0.85 to –4.4

62. With the exception of the analysis with the 40 year lag, all runs show significant net benefits (shown as a negative in the table), though in all cases ranges as defined by the 95% confidence intervals cross zero. The probability of benefits exceeding costs is summarised below.

Table 7.10: Probability of net benefit for Measure B under different assumptions, against single point estimates of costs and a range drawn from evidence of ex-ante/ex-post comparison.

		Probability of net benefit	
	Description of scenario	above single point costs	above costs (with range 50% to 120% for costs)
1	Lag = 40 years	26%	32%
2	Variable lag, 30% in 5 years	58%	63%
3	Variable lag, 50% in 5 years	61%	65%
4	Lag = 0 years	65%	69%
5	Variable lag, 30% in 5 years + climate	55%	60%
6	Variable lag, 30% in 5 years + CAFE morbidity + climate	69%	72%
7	Variable lag, 50% in 5 years + climate	57%	62%
8	Variable lag, 50% in 5 years + CAFE morbidity + climate	70%	74%

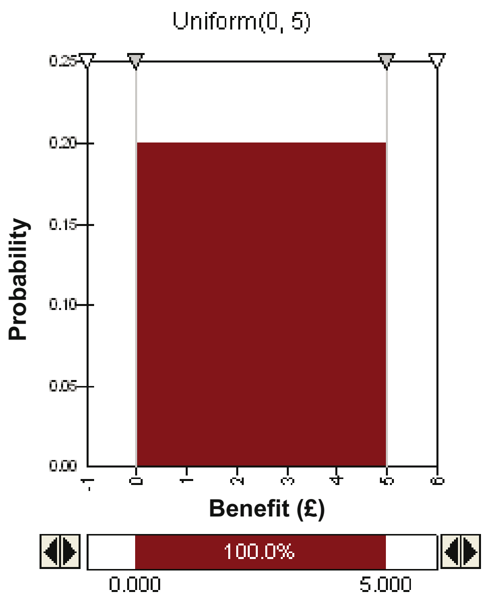
63. What probability of gaining a net benefit is sufficient to justify taking action? Some may accept anything greater than 50%; some may accept a lower figure (perhaps in recognition of the omitted benefits); others may require a higher figure (perhaps through concern over effects on industry). It is not, however, a scientific decision. Some further information on this is provided in Appendix 1 section 2, drawing on the position recently adopted in reports of the Intergovernmental Panel on Climate Change (IPCC).

Appendix 1: Interpretation of Probability Distributions

1. Interpreting probability distribution graphs

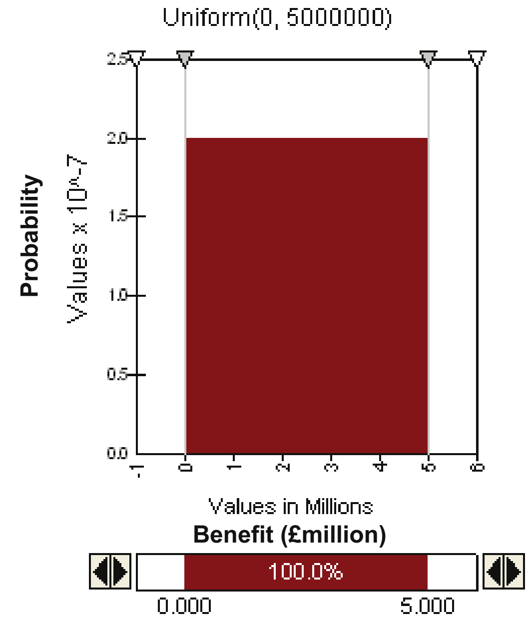
64. Two types of graph are used here to show probability distributions for input variables and outputs. The first shows probability density (used for the input variables), and the second relative probability (used for outputs). Taking probability density curves first, three graphs (Figures A, B and C) are presented below. For ease of understanding, Figures A and B use a uniform distribution. In the case of Figure A this ranges from £0 to £5, with all values in the range having an equal (i.e. uniform) probability of occurrence. The *y*-axis between 0 and 5 reads 0.2. What this actually means is that the probability of each group of values with an interval of 1 unit (£0 to £1, £1 to £2, £2 to £3, £3 to £4 and £4 to £5) is 0.2. The total probability is then 0.2 x 5 (as there are 5 groups of values) = 1, which it has to be by definition.

Figure A



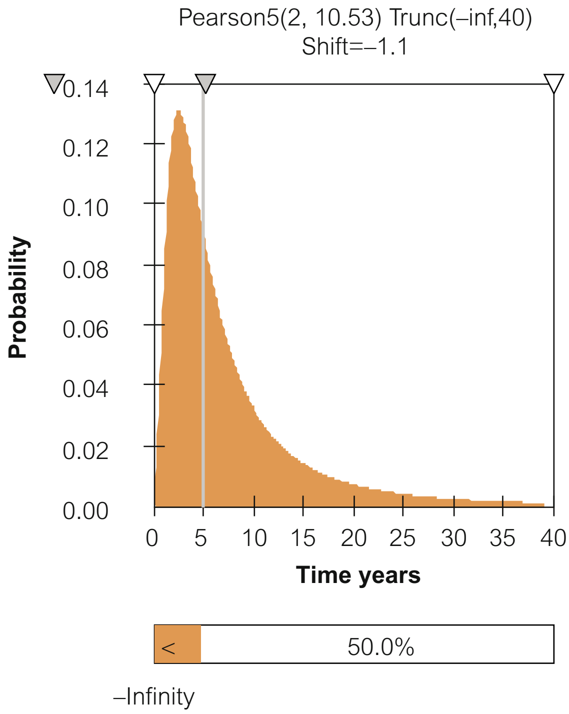
65. In Figure B a uniform distribution is again taken, with benefits between £0 and £5million. In this case the *y*-axis probability over this range reads $2x10^{-7}$, one million times smaller than the probability shown in Figure A. What this means of course is that the probability of each group of values with an interval of 1 unit (£0 to £1, £1 to £2 … £499,998 to £499,999 and £4,999,999 to £5,000,000) is $2x10^{-7}$. The total probability again equals 1 ($2x10^{-7}$ x 5 million).

Figure B



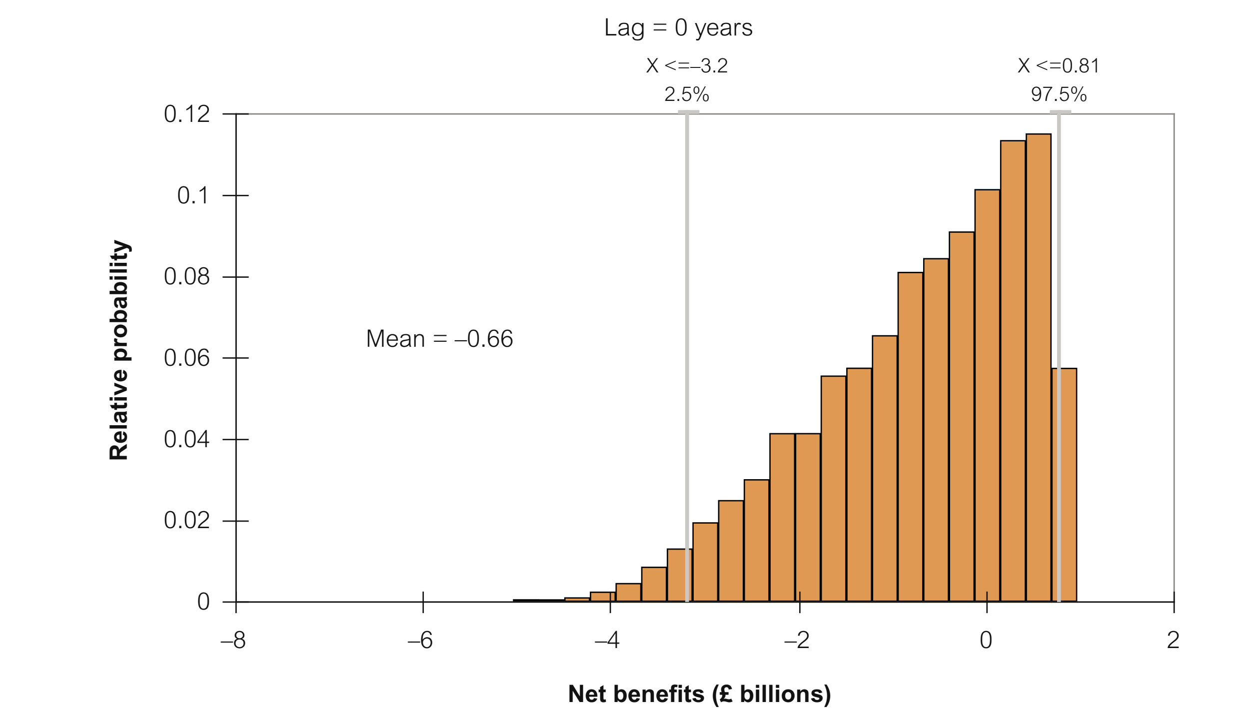
66. The distributions used in this report are not uniform like in Figures A and B, but more complex, such as the normal distribution shown in Figure C. However, the same applies, with the *y*-axis showing the probability of any group of values with an interval of 1 unit.

Figure C



67. In contrast, the relative probability figures, used for outputs, show the probability of values occurring within each bar of a histogram (Figure D).

Figure D



68. Adding the probability for all bars of the histogram generates a total probability of 1. The width of each bar varies according to the range in benefits or net benefits. Irrespective of precisely how the figures are drawn, they all show the same thing – how values within a distribution are spread within their range.

2. What level of probability is sufficient to justify action being taken?

69. Whilst the scientific analysis can go so far in quantifying results and providing guidance on the probability of different outcomes, it is for policy makers to decide what level of probability (e.g. of benefits exceeding costs, as here) is sufficient to justify a specific course of action being followed. The IPCC (Intergovernmental Panel on Climate Change) raised concern some time ago about the subjective use of terms such as "likely", "very unlikely", etc. The recently published '*Summary for Policy Makers*'[10] from IPCC Working Group I, part of the IPCC's Fourth Assessment Report standardises the terminology as follows:

- *Extremely likely* > 95%,
- *Very likely* > 90%,
- *Likely* > 66%,
- *More likely than not* > 50%,
- *Unlikely* < 33%,
- *Very unlikely* < 10%,
- *Extremely unlikely* < 5%

[10] http://ipcc-wg1.ucar.edu/wg1/docs/WG1AR4_SPM_Approved_05Feb.pdf

70. Note that there is a gap between 33% and 50%, which could presumably be described as "*Less likely than true*", but is still above "*Unlikely*".

71. Results of course remain subject to modelling and other biases, which also need to be taken into account. None of this of course passes judgement on what represents a sufficient probability to take action, but it does perhaps provide an easier framework against which to assess probabilities.

3. The Beta (Generalised) distribution[11]

Beta (Generalized)

RISKBetaGeneral(α1, α2, min, max)

Parameters:

α_1	continuous shape parameter	$\alpha_1 > 0$
α_2	continuous shape parameter	$\alpha_2 > 0$
min	continuous boundary parameter	min < max
max	continuous boundary parameter	

Domain:

$\min \le x \le \max$ — continuous

Density and Cumulative Distribution Functions:

$$f(x) = \frac{(x-\min)^{\alpha_1 - 1}(\max - x)^{\alpha_2 - 1}}{B(\alpha_1, \alpha_2)(\max - \min)^{\alpha_1 + \alpha_2 - 1}}$$

$$F(x) = \frac{B_z(\alpha_1, \alpha_2)}{B(\alpha_1, \alpha_2)} \equiv I_z(\alpha_1, \alpha_2) \qquad \text{with } z \equiv \frac{x - \min}{\max - \min}$$

where B is the *Beta Function* and B_z is the *Incomplete Beta Function*.

Mean:

$$\min + \frac{\alpha_1}{\alpha_1 + \alpha_2}(\max - \min)$$

Variance:

$$\frac{\alpha_1 \alpha_2}{(\alpha_1 + \alpha_2)^2(\alpha_1 + \alpha_2 + 1)}(\max - \min)^2$$

[11] This appendix is reproduced from information given in the @RISK function manual.

Skewness:

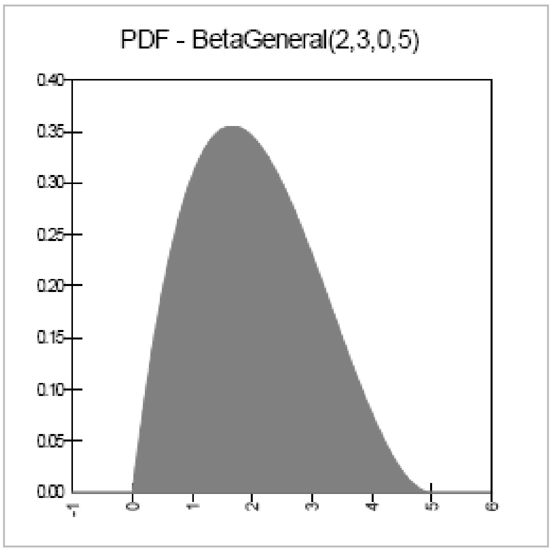
$$2\frac{\alpha_2-\alpha_1}{\alpha_1+\alpha_2+2}\sqrt{\frac{\alpha_1+\alpha_2+1}{\alpha_1\alpha_2}}$$

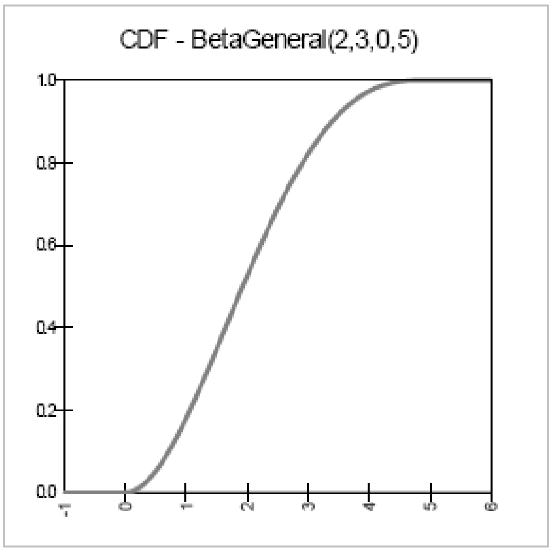
Kurtosis:

$$3\frac{(\alpha_1+\alpha_2+1)\left(2(\alpha_1+\alpha_2)^2+\alpha_1\alpha_2(\alpha_1+\alpha_2-6)\right)}{\alpha_1\alpha_2(\alpha_1+\alpha_2+2)(\alpha_1+\alpha_2+3)}$$

Mode:

$\min+\frac{\alpha_1-1}{\alpha_1+\alpha_2-2}(\max-\min)$	$\alpha_1>1,\ \alpha_2>1$
min	$\alpha_1<1,\ \alpha_2\geq1$ or $\alpha_1=1,\ \alpha_2>1$
max	$\alpha_1\geq1,\ \alpha_2<1$ or $\alpha_1>1,\ \alpha_2=1$





Appendix 2: Possible distributions for the chronic mortality function

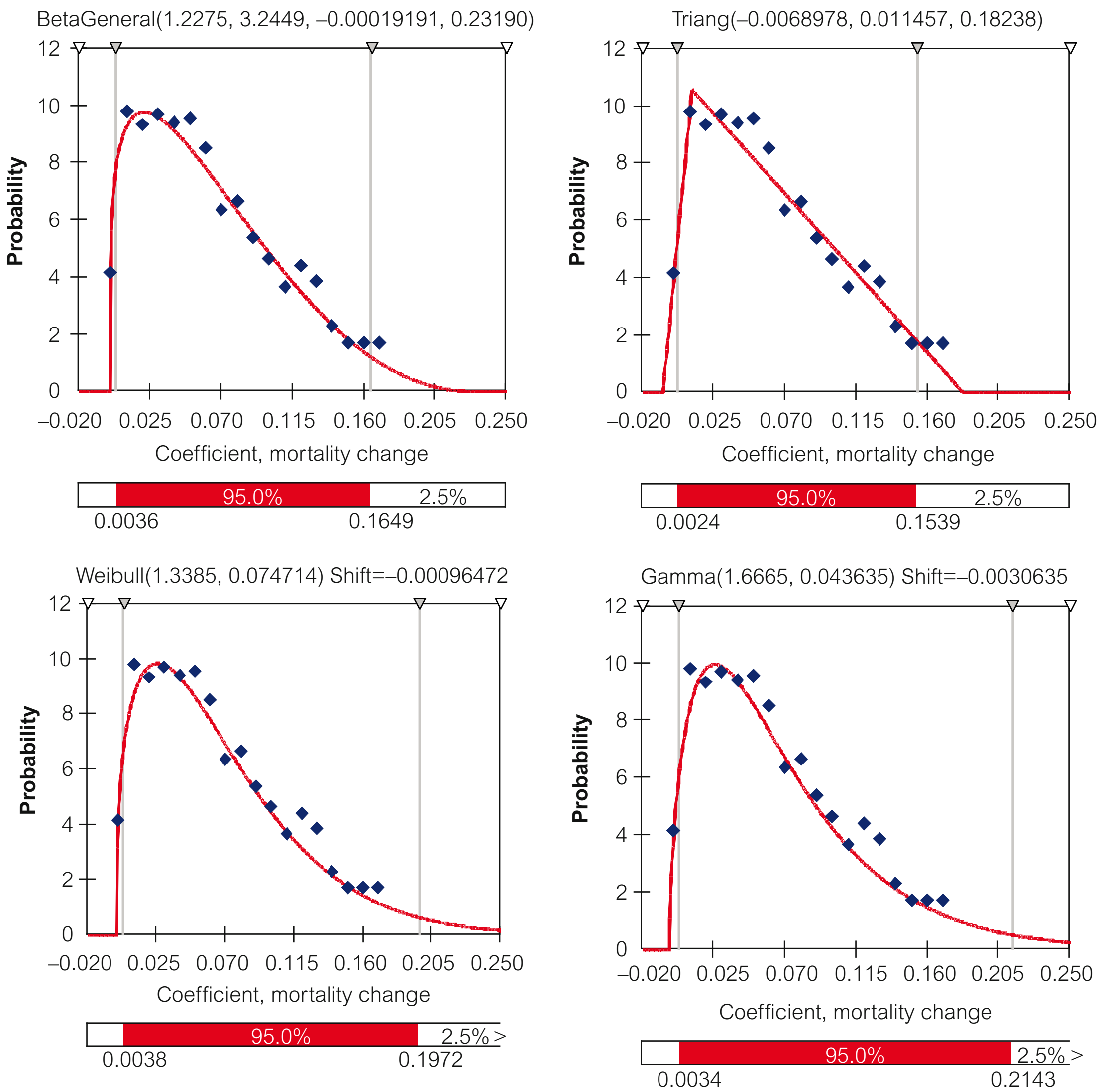
72. The graphs that follow show the various probability distributions considered as a match to the COMEAP output on the probability of the coefficient for chronic mortality effects (relative risk coefficient) of particles being of various sizes. They start with the Beta (Generalised) distribution which gives the best fit of all those assessed. A further 11 distributions are shown of increasingly worse fit, down to the Uniform distribution, as follows:

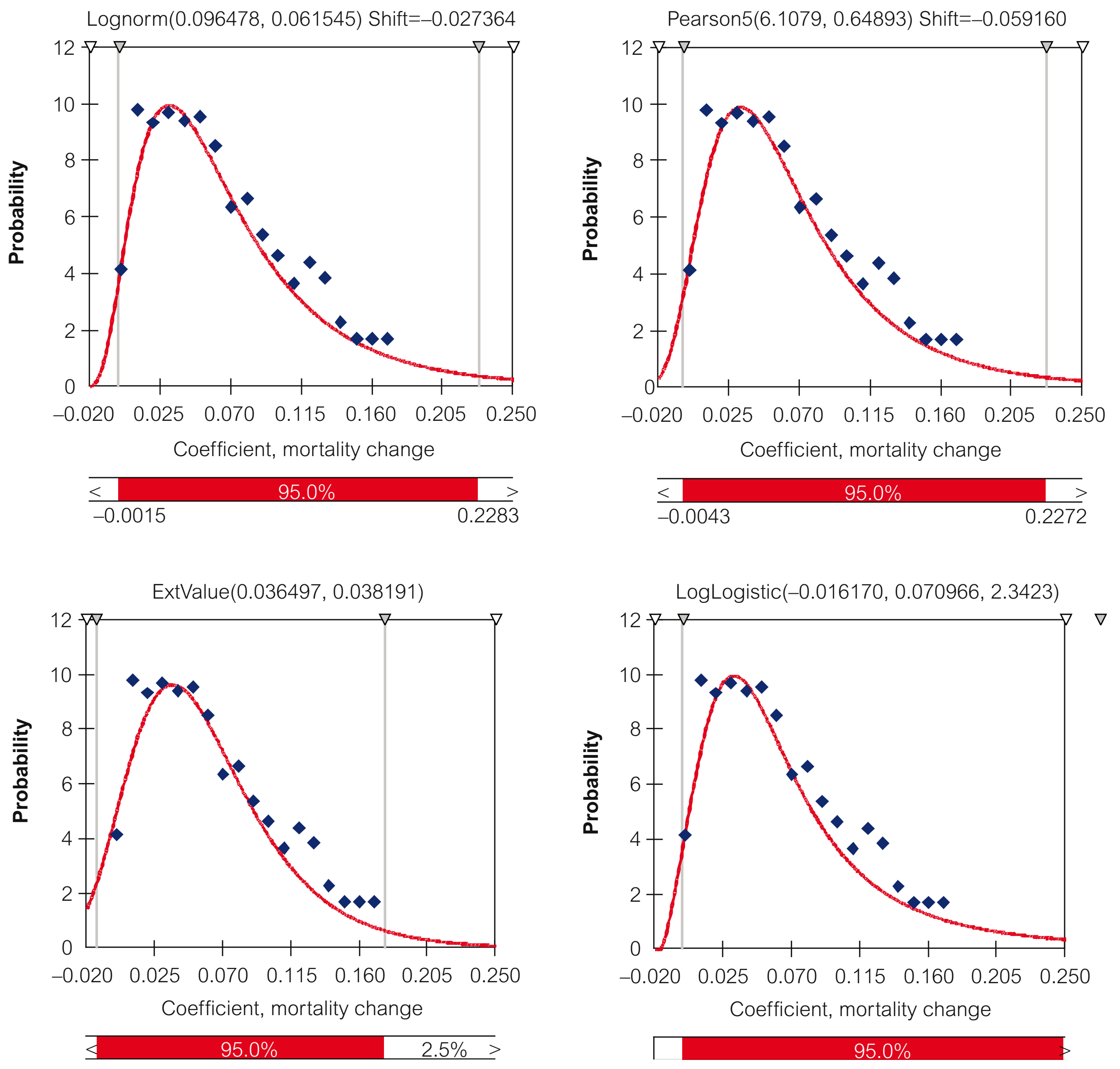
    1. Beta generalised (best fit), mean = 6.4%
    2. Triangular, mean = 6.2%
    3. Weibull, mean = 6.8%
    4. Gamma, mean = 7.0%
    5. Lognormal, mean = 6.9%
    6. Pearson5, mean = 6.8%
    7. Extreme value, mean = 5.9%
    8. Loglogistic, mean = 8.2%
    9. Normal, mean = 4.5%
    10. Logistic, mean = 4.4%
    11. Exponential, mean = 9.6%
    12. Uniform (worst fit), mean = 6.4%

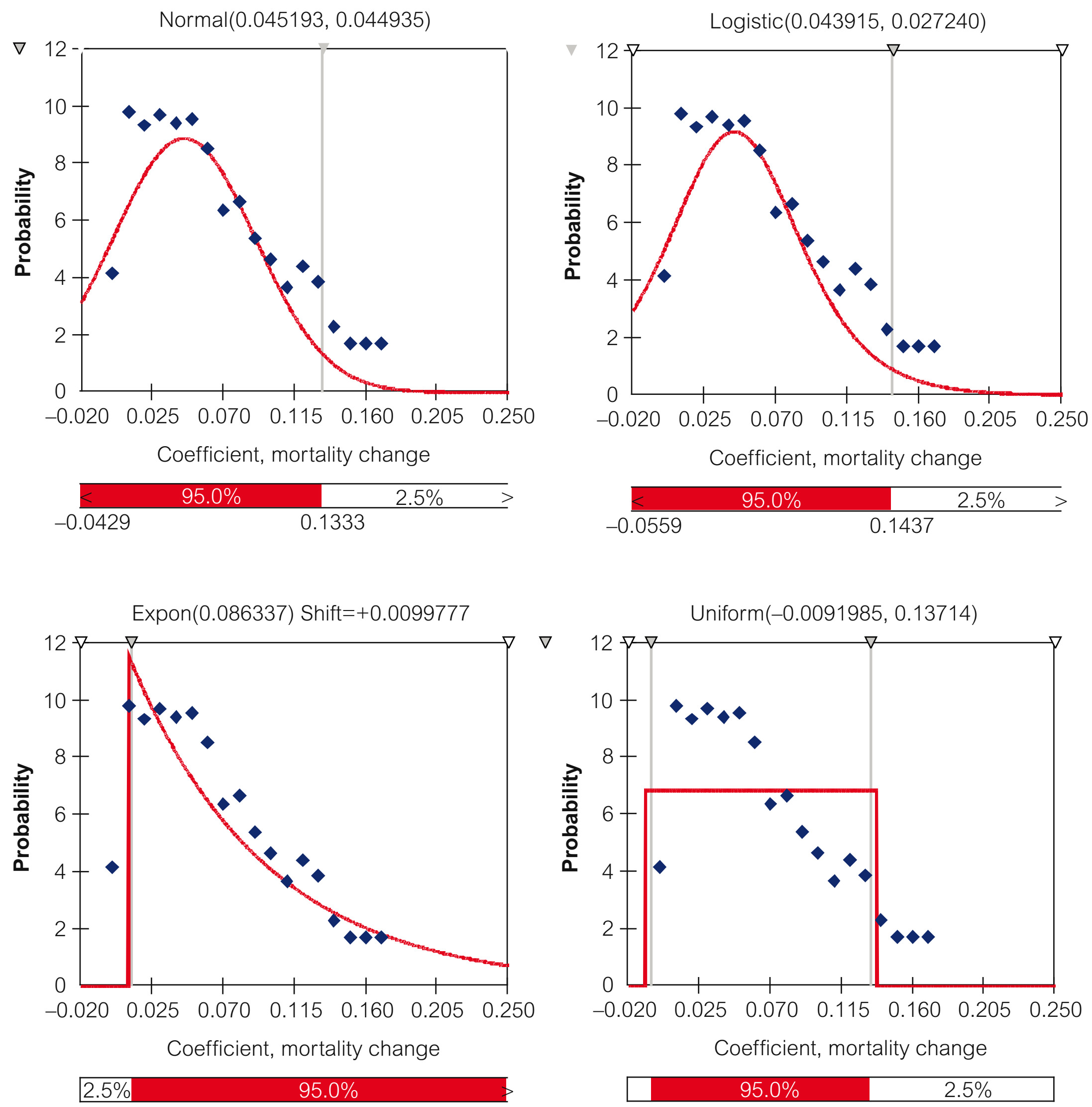
73. The mean values are shown (expressed as %) for comparison with the COMEAP best estimate of 6%. The closest distributions are (in order) Triangular, Beta general, Uniform and Extreme value. No other distribution provides a mean within 0.5% of the COMEAP best estimate.

74. The heading to each graph below shows the values of the parameters that define the distribution, in addition to the name of the distribution considered. To take a simple example, the heading to the second graph (for the triangular distribution) describes the minimum value (–0.00689), the most likely value (0.0115) and the maximum value (0.182).

75. It is notable that the second best fit is achieved with a triangular distribution. In the interests of simplicity this may be preferable to the Beta function that gives best fit. In the context of the current work, it has the advantage of being constrained more tightly to the range considered by COMEAP.


BetaGeneral(1.2275, 3.2449, –0.00019191, 0.23190)
Probability
Coefficient, mortality change
95.0%
2.5%
0.0036
0.1649
Triang(–0.0068978, 0.011457, 0.18238)
Probability
Coefficient, mortality change
95.0%
2.5%
0.0024
0.1539
Weibull(1.3385, 0.074714) Shift=–0.00096472
Probability
Coefficient, mortality change
95.0%
2.5%
0.0038
0.1972
Gamma(1.6665, 0.043635) Shift=–0.0030635
Probability
Coefficient, mortality change
95.0%
2.5%
0.0034
0.2143


Lognorm(0.096478, 0.061545) Shift=–0.027364
Probability
Coefficient, mortality change
95.0%
–0.0015
0.2283
Pearson5(6.1079, 0.64893) Shift=–0.059160
Probability
Coefficient, mortality change
95.0%
–0.0043
0.2272
ExtValue(0.036497, 0.038191)
Probability
Coefficient, mortality change
95.0%
2.5%
LogLogistic(–0.016170, 0.070966, 2.3423)
Probability
Coefficient, mortality change
95.0%


Normal(0.045193, 0.044935)
Probability
Coefficient, mortality change
95.0%
2.5%
–0.0429
0.1333
Logistic(0.043915, 0.027240)
Probability
Coefficient, mortality change
95.0%
2.5%
–0.0559
0.1437
Expon(0.086337) Shift=+0.0099777
Probability
Coefficient, mortality change
2.5%
95.0%
Uniform(–0.0091985, 0.13714)
Probability
Coefficient, mortality change
95.0%
2.5%

Appendix 3: Uncertainty and the impact-pathway approach

76. The main strength of the impact-pathway approach (see figure) is that it goes through a logical chain looking at burdens (e.g. emissions), through dispersion and exposure to quantification of impacts and valuation.

Identity sources and quantify emissions of NOx and VOCs

↓

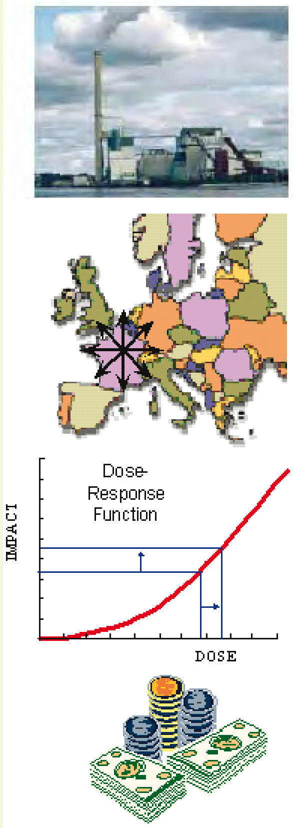
Calculate dispersion of precursors and ozone concentrations across Europe

↓

Apply exposure-response functions to estimate yield loss

↓

Value yield loss using world market prices



77. Impacts and damages under any scenario are calculated using the following general relationship

Impact = pollution x stock at risk x response function

Economic damage = impact x unit value of impact

78. Pollution may be expressed in terms of concentration or deposition. The term 'stock at risk' relates to the amount of sensitive material (people, ecosystems, materials, etc.) present in the modelled domain (the receiving environment). Calculations are normally made for each cell within a grid system generated by dispersion modelling, often using GIS.

79. Although the underlying form of the above equation does not change, the precise form of the equation varies for different types of impact. For example, the functions for materials damage from acidic deposition require consideration of climatic variables (such as relative humidity) and several pollutants simultaneously. For any receptor group (human health, crops, materials, etc.) it is necessary to implement a number of these impact-pathways to generate overall benefits. So in the case of impacts of ozone on crop yield, it is necessary to consider impacts on a series of different crops, each of which differs in sensitivity. For health assessment it is necessary to quantify across a series of different effects to understand the overall impact of air pollution on the population.

80. The final stage, valuation, is generally done from the perspective of 'willingness to pay' (WTP). For some effects, such as damage to crops, or to buildings of little or no cultural merit this can be done using appropriate market data. Some elements of the valuation of health impacts can also be quantified from market data (e.g. the cost of medicines and care), though other elements such as willingness to pay to avoid being ill in the first place are clearly not quantifiable from such sources. In such cases alternative methods are necessary for the quantification, such as the use of contingent valuation. Note in the case of non-market effects, such as health, the approach adopts benefits transfer from primary studies (e.g. of mortality or morbidity).

81. Uncertainty may take several forms:

- Statistical uncertainty, reflecting the variability in the measured data that provide input to the analysis.
- Sensitivity to methodological assumptions, such as what morbidity functions to include in the analysis.
- Bias arising from unquantified elements in the analysis (e.g. ecological impacts, damage to cultural heritage).

82. Uncertainty is present at all stages of the impact-pathway:

- Uncertainty in emission estimates may occur over the implementation of the policy itself (e.g. due to compliance rates, exemptions), or may occur in estimation of emissions, either in terms of unit emission factors or aggregation of emissions from policies.
- Uncertainty in modelling through uncertainty in input data (e.g. meteorological conditions which can vary greatly between years) and in the mathematical representation of dispersion processes and atmospheric chemistry.
- Uncertainty in the stock at risk, e.g. population. For example, from geographical resolution, or from the uncertainties associated with future population growth, or from updating projections to take into account migration.
- Impact functions. There are multiple levels of uncertainty here. Firstly, whether effects are included or not (e.g. which health impacts). Second the form and slope of the relationship (e.g. threshold, slope, linearity) – which is itself a function of the uncertainty in the underlying epidemiological studies.

- Valuation, through uncertainty in the underlying primary valuation studies (e.g. the stated preference values) and in benefits transfer.

83. There is also uncertainty in the way that policies are implemented – this has been identified by several ex post reviews as a key factor. For example, there is often variability between policies as planned, adopted and implemented, including differences in interpretation of targets and measures; in policy instruments; and in the extent of compliance or objectives achievement – e.g. through compliance rates or exemptions. There are also inaccuracies in the assumptions made on the number of businesses/individuals affected by the policies and measures.

84. We have also not considered the uncertainty in projections, most notably the uncertainties in counterfactual scenarios – these are also key to differences found in comparative ex post/ex ante studies. As an illustration, benefits are influenced by other policies interacting with (and changing) actual out-turns of benefits. For accurate assessment of uncertainty in benefits, there is a need to take into account confounding factors and parameters, such as economic growth, technological change, policy developments, the interactions and interdependencies between measures, the presence of side-effects, or the difficulty of relating measures to outcomes.

85. One final area of uncertainty that is potentially relevant here is omitted categories. Three areas are highlighted:

    - Secondary organic aerosols from VOC emissions. Analysis of this omitted category has been shown in sensitivity analysis to be potentially important. This could affect some of the priorities in the ranking of different measures.
    - Potential toxicity variations across the particulate mixture. There is growing evidence that different elements of the particulate mixture have different toxicity (the difference between primary, secondary sulphates, secondary nitrate particles). The evidence seems to be indicating that primary particulate matter is of most concern.
    - The consideration of other morbidity health endpoints, for example comparing the difference between the CAFE HIA set and the COMEAP HIA set.
    - The consideration of benefits for ecosystems.

86. The multiplicative nature of the analysis (concentration x population x response function x valuation) inevitably leads to expansion of uncertainty through the impact-pathway chain. However, uncertainty operates in two directions for each parameter, with the result that errors cancel out to some degree.

87. One may be tempted to ask why bother with analysis if it is subject to so many sources of uncertainty – can analysis lead to more robust decision making, or does it mean that any faith placed in analysis is unwarranted? The impact-pathway approach enables uncertainties at each stage of the analysis to be identified. They can then be described quantitatively or qualitatively, and their combined effect assessed. The following outcomes are then possible through the CBA:

1. Quantified benefits are clearly greater than costs with no or negligible overlap in ranges.

2. Costs are clearly greater than quantified benefits with no or negligible overlap in ranges.

3. There is significant overlap in the ranges of costs and quantified benefits.

88. For the first position the CBA, despite underlying uncertainties, would point firmly in the direction of taking the action under investigation. In the second position, the reverse applies, unless it is argued that the unquantified benefits are sufficiently large that they would change the balance. Only in the third case does the existence of uncertainty seem likely to have a substantial effect on the decision making process, and even then, the analysis provides useful information by demonstrating this to be the case.

Appendix 4: Results

Measure R: Benefits

Figure 7.14

Annualised benefits of Measure R, 40 year lag for mortality impacts.
Annual present value £ billion. 95% confidence interval shown

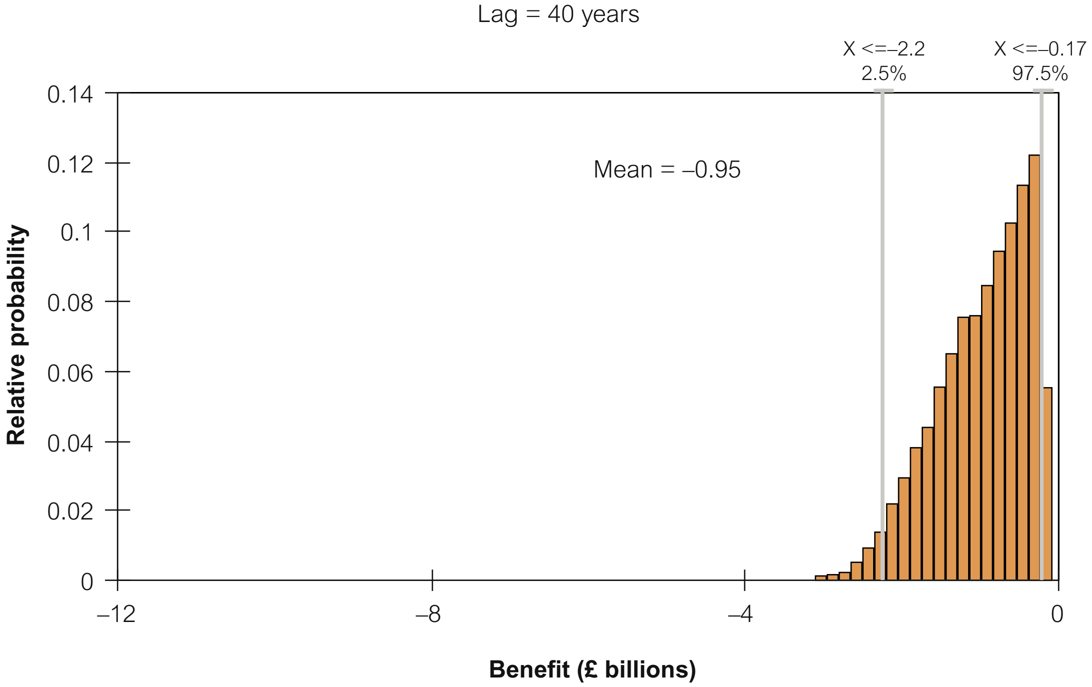


Figure 7.15

Annualised benefits of Measure R, lag for mortality impacts distributed over 40 years with 30% coming in the first 5 years. Annual present value £ billion

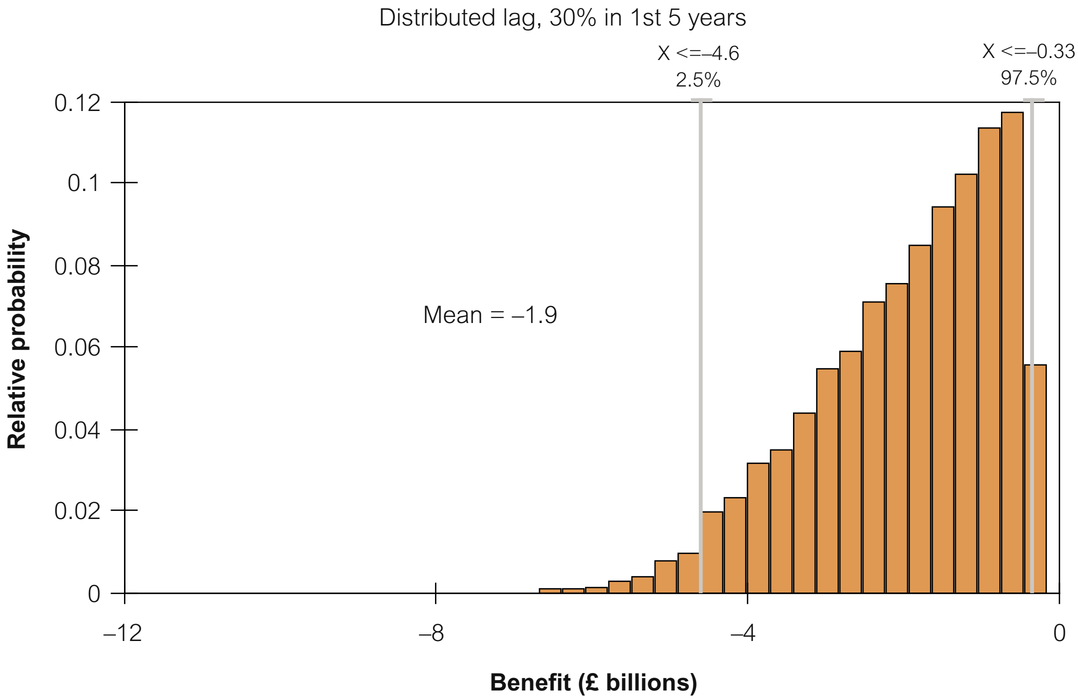


Figure 7.16

Annualised benefits of Measure R, lag for mortality impacts distributed over 40 years with 50% coming in the first 5 years. Annual present value £ billion

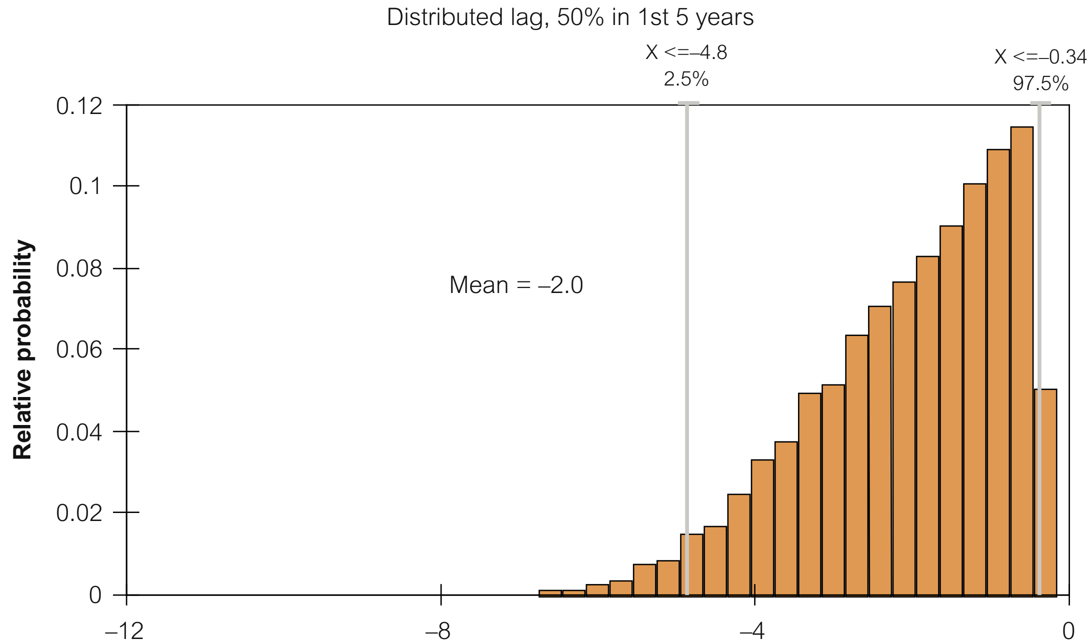


Figure 7.17

Annualised benefits of Measure R, no lag for mortality impacts. Annual present value £ billion

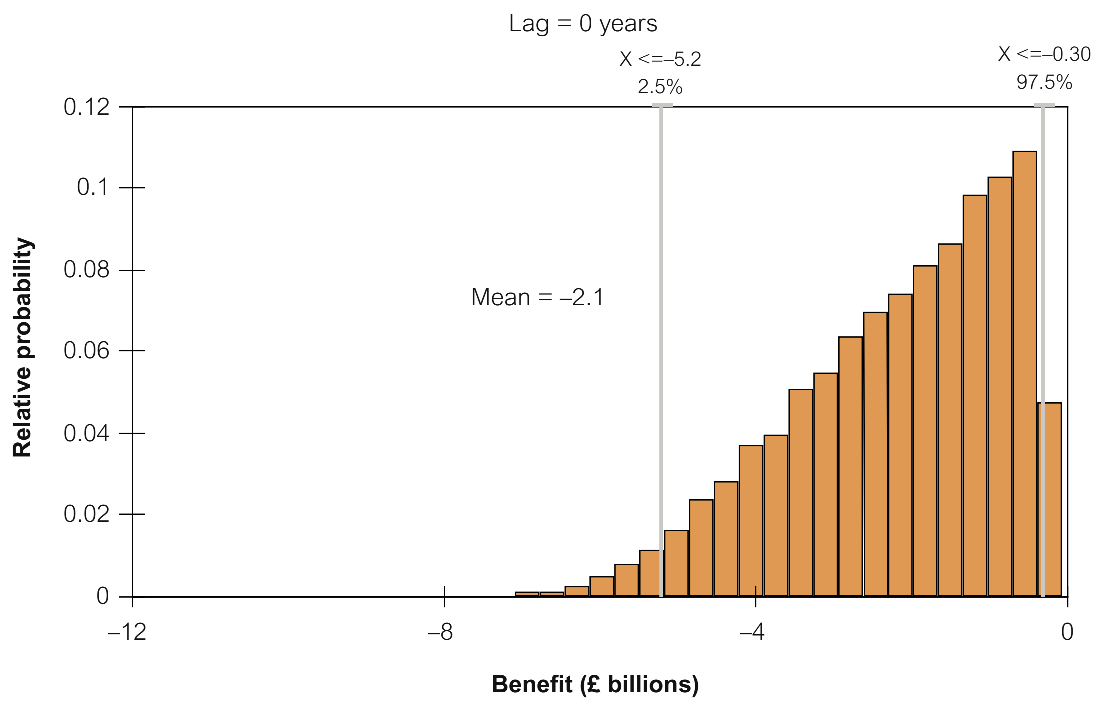


Figure 7.18

Annualised benefits of Measure R, lag for mortality impacts distributed over 40 years with 30% coming in the first 5 years with climate benefits added. Annual present value £ billion

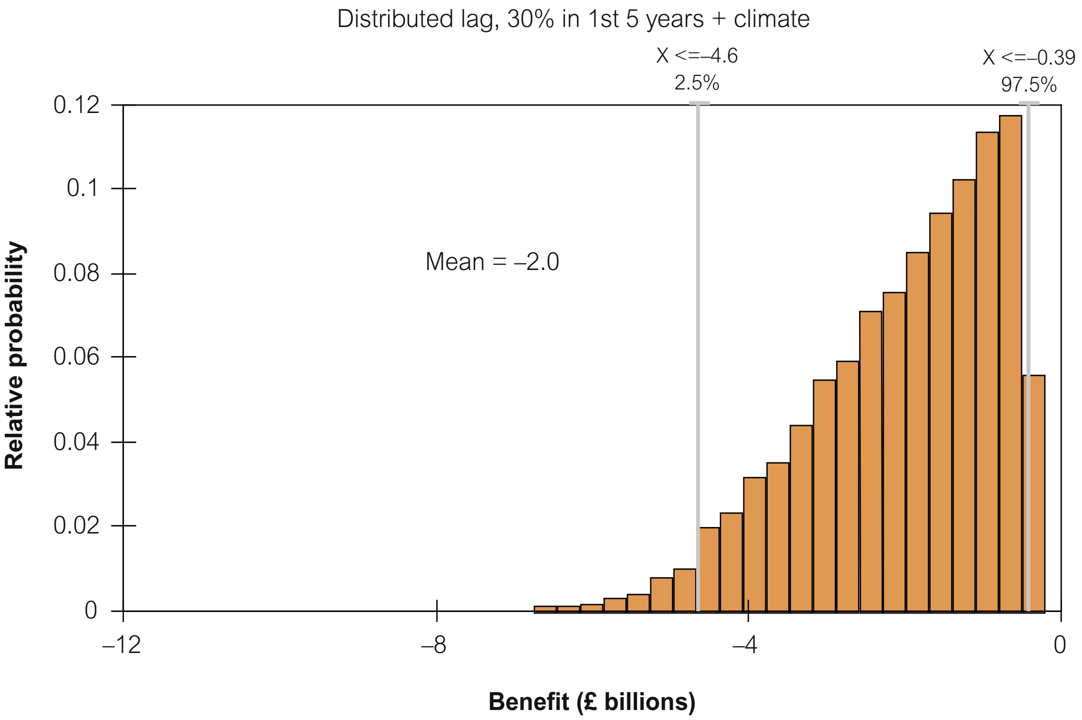


Figure 7.19

Annualised benefits of Measure R, lag for mortality impacts distributed over 40 years with 30% coming in the first 5 years with climate benefits and CAFE morbidity benefits added. Annual present value £ billion

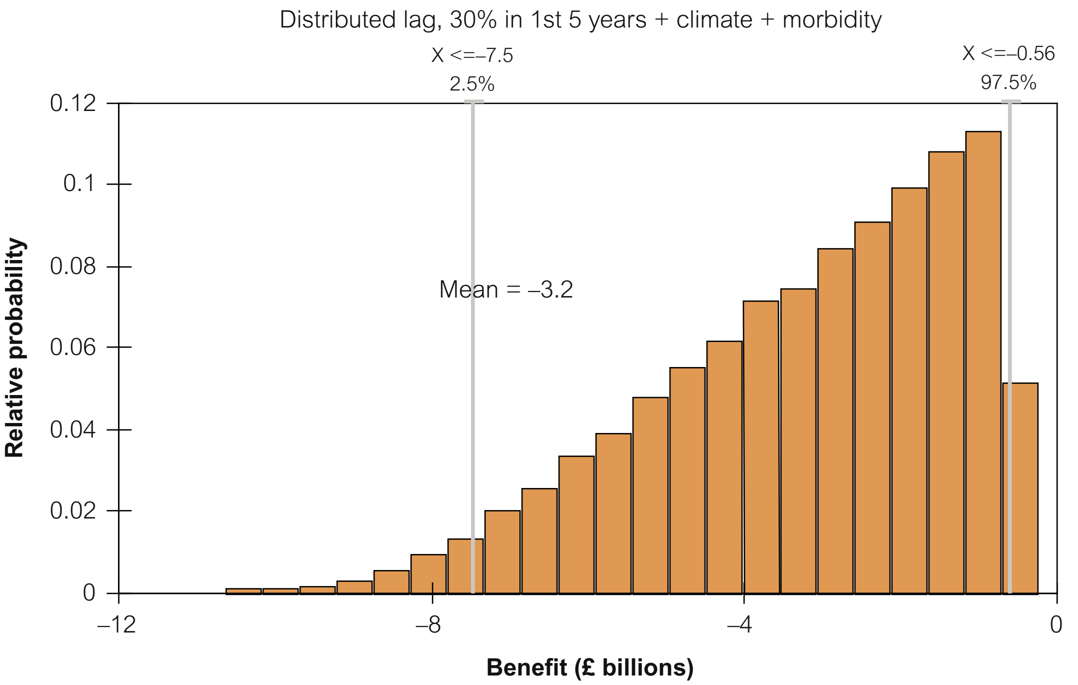


Figure 7.20

Annualised benefits of Measure R, lag for mortality impacts distributed over 40 years with 50% coming in the first 5 years with climate benefits added. Annual present value £ billion

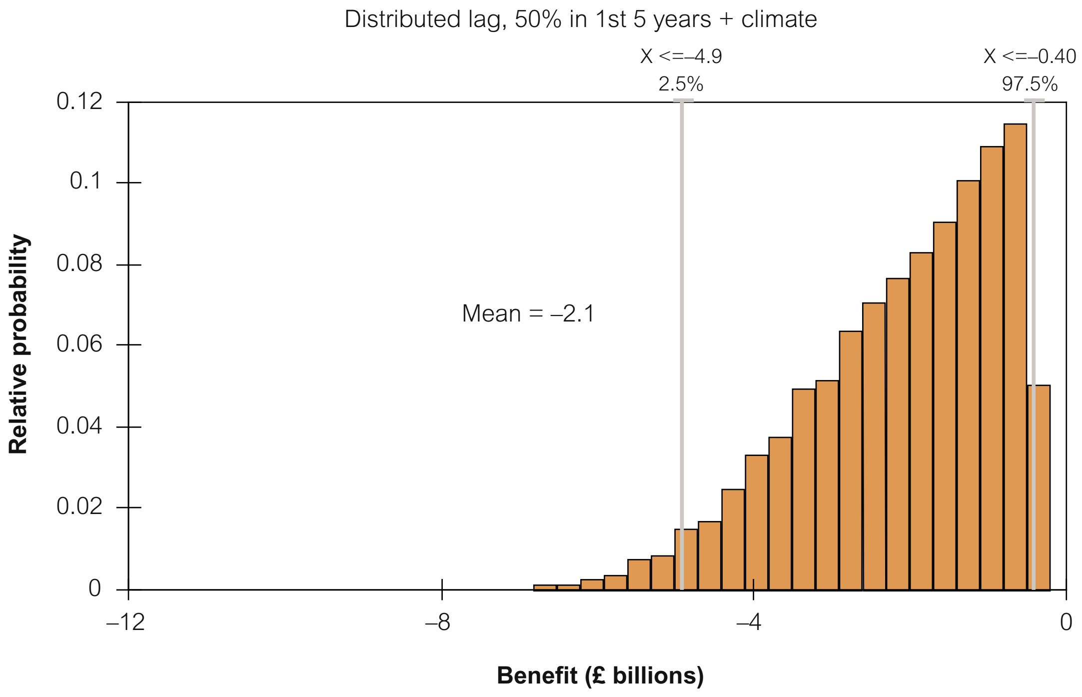
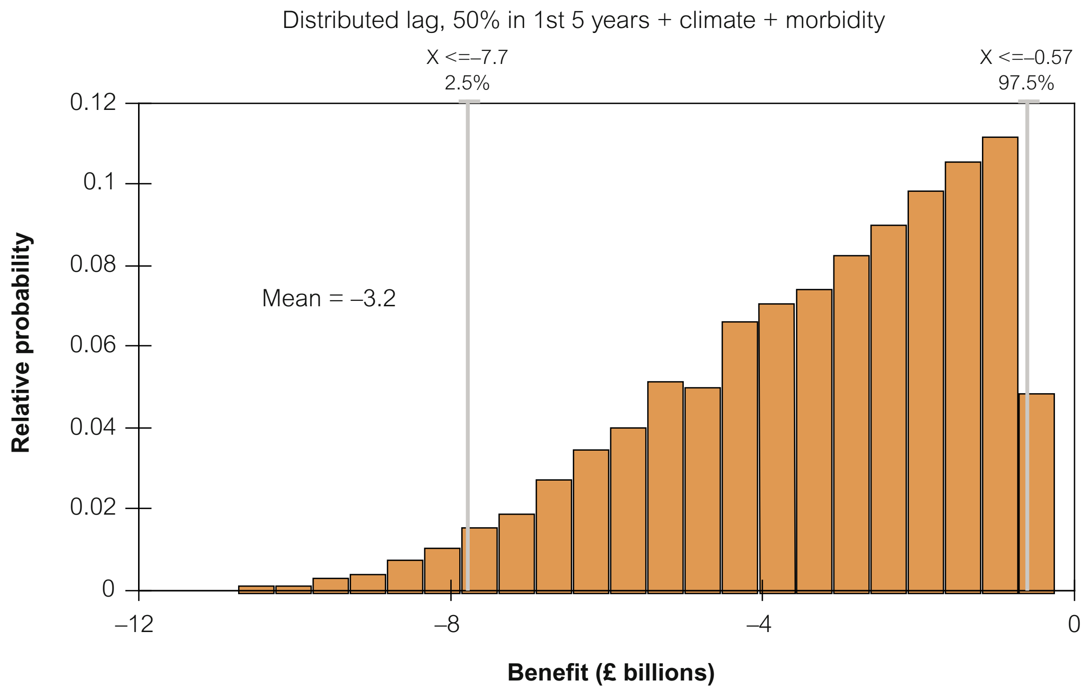


Figure 7.21

Annualised benefits of Measure R, lag for mortality impacts distributed over 40 years with 50% coming in the first 5 years with climate benefits and CAFE morbidity benefits added. Annual present value £ billion



Net benefits for Measure R

Figure 7.22

Annualised net benefits of Measure R, 40 year lag for mortality impacts. Annual present value £ billion

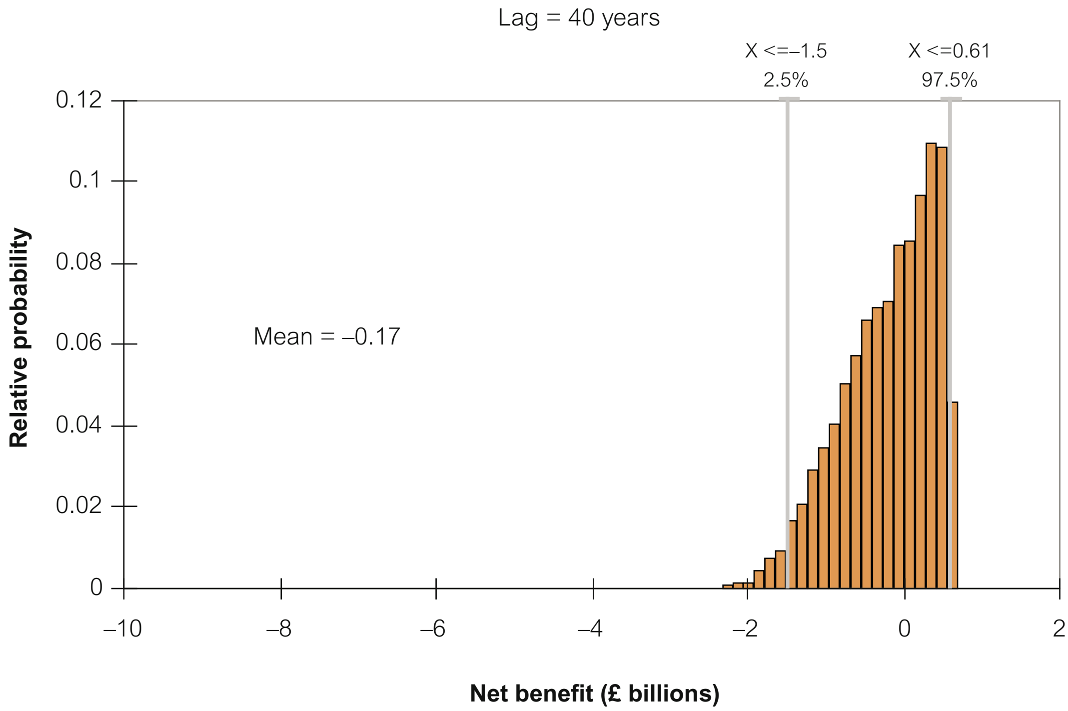


Figure 7.23

Annualised net benefits of Measure R, lag for mortality impacts distributed over 40 years with 30% coming in the first 5 years. Annual present value £ billion

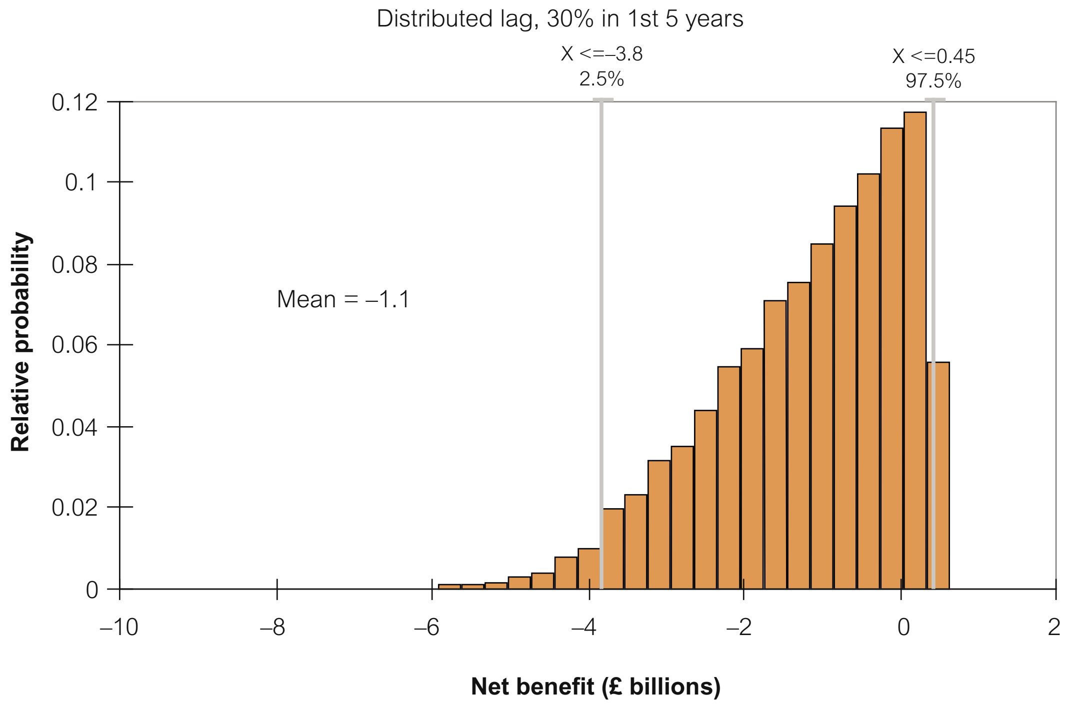


Figure 7.24

Annualised net benefits of Measure R, lag for mortality impacts distributed over 40 years with 50% coming in the first 5 years., Annual present value £ billion

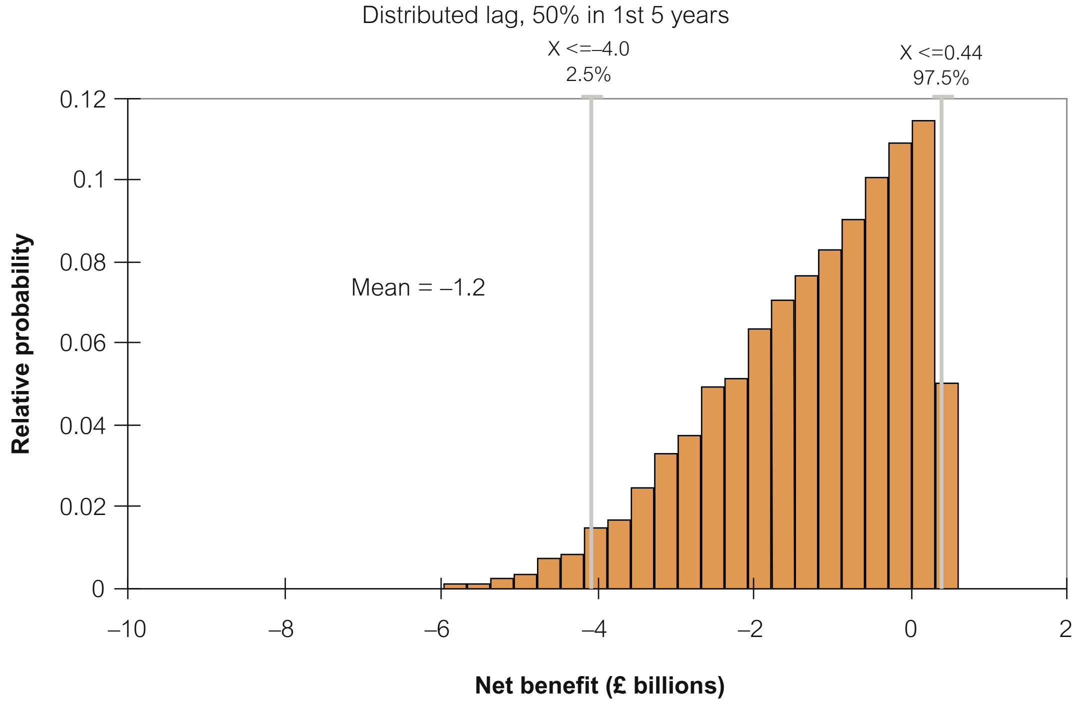


Figure 7.25

Annualised net benefits of Measure R, no lag for mortality impacts. Annual present value £ billion

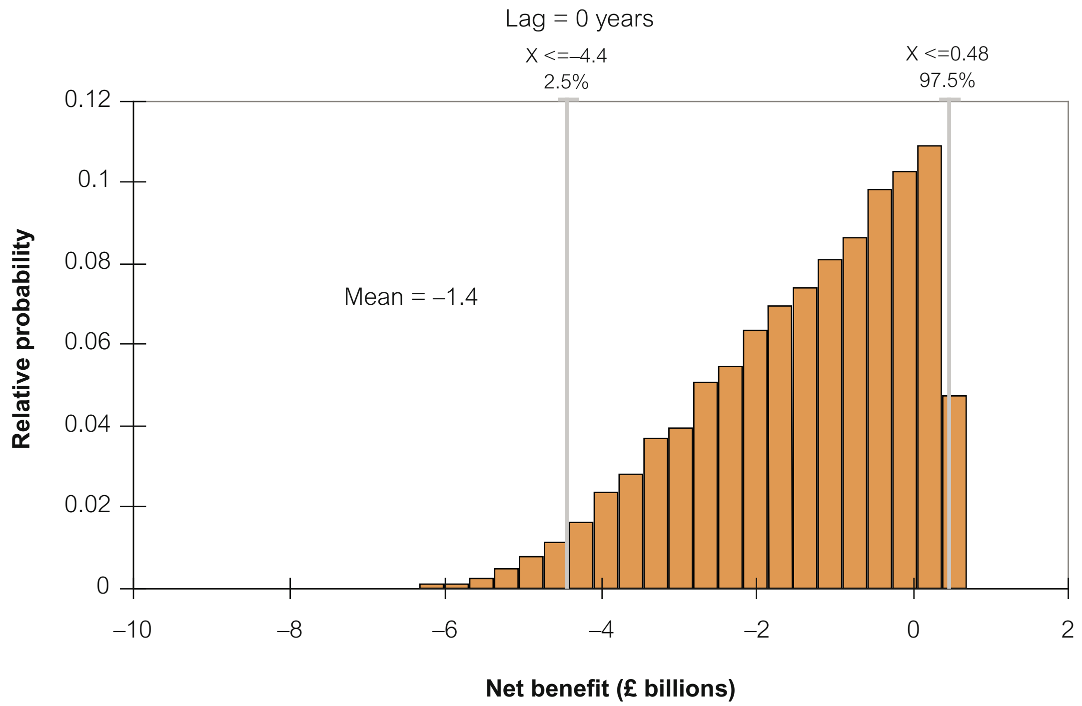


Figure 7.26

Annualised net benefits of Measure R, lag for mortality impacts distributed over 40 years with 30% coming in the first 5 years with climate benefits added. Annual present value £ billion

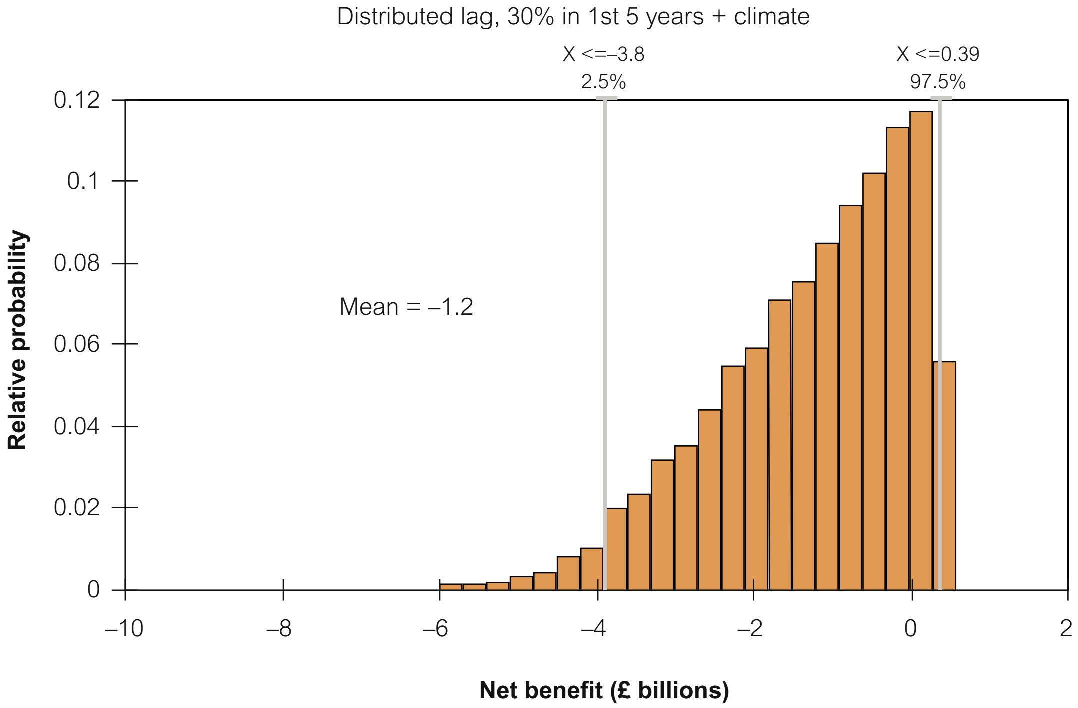


Figure 7.27

Annualised net benefits of Measure R, lag for mortality impacts distributed over 40 years with 30% coming in the first 5 years with climate benefits and CAFE morbidity benefits added. Annual present value £ billion

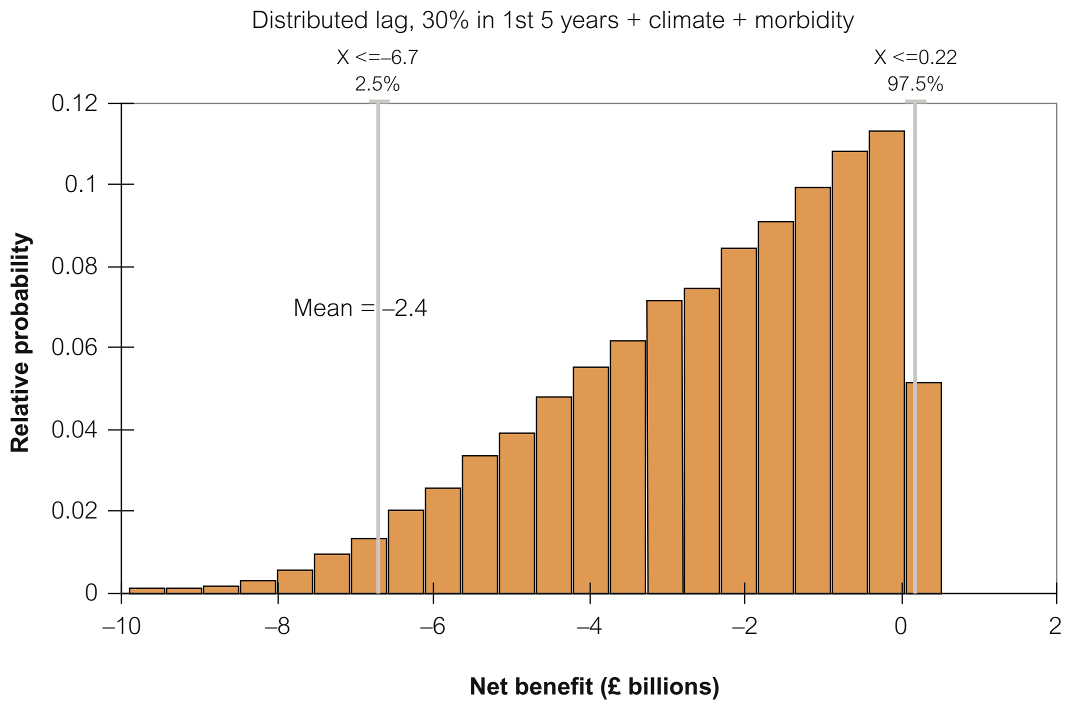


Figure 7.28

Annualised net benefits of Measure R, lag for mortality impacts distributed over 40 years with 50% coming in the first 5 years with climate benefits added. Annual present value £ billion

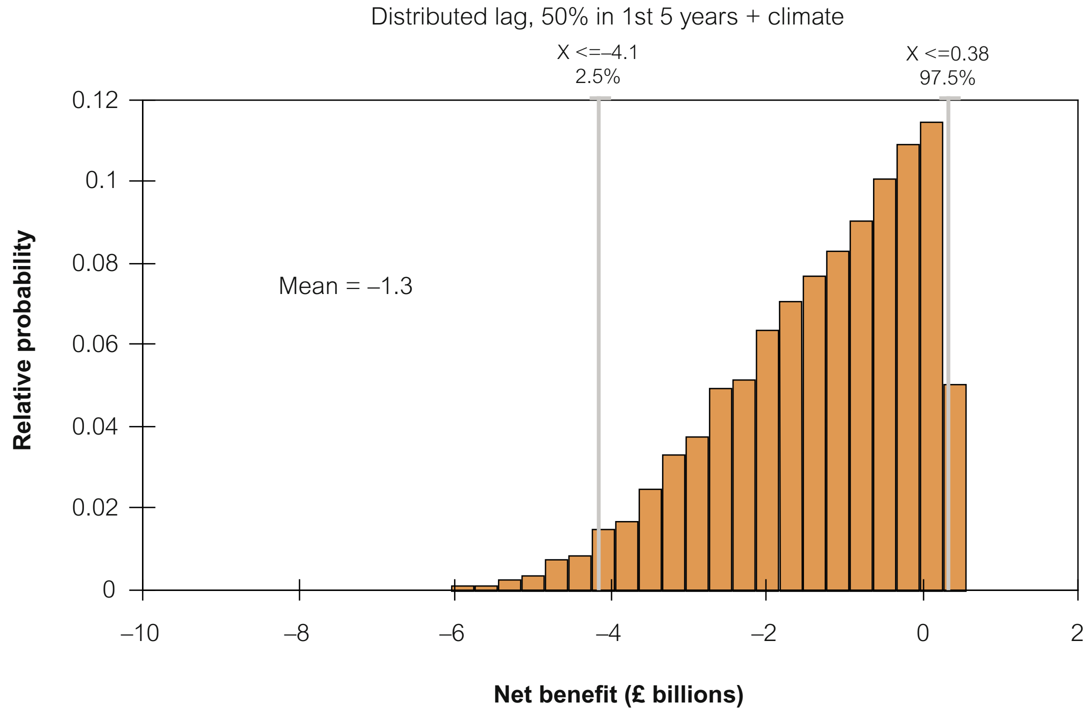
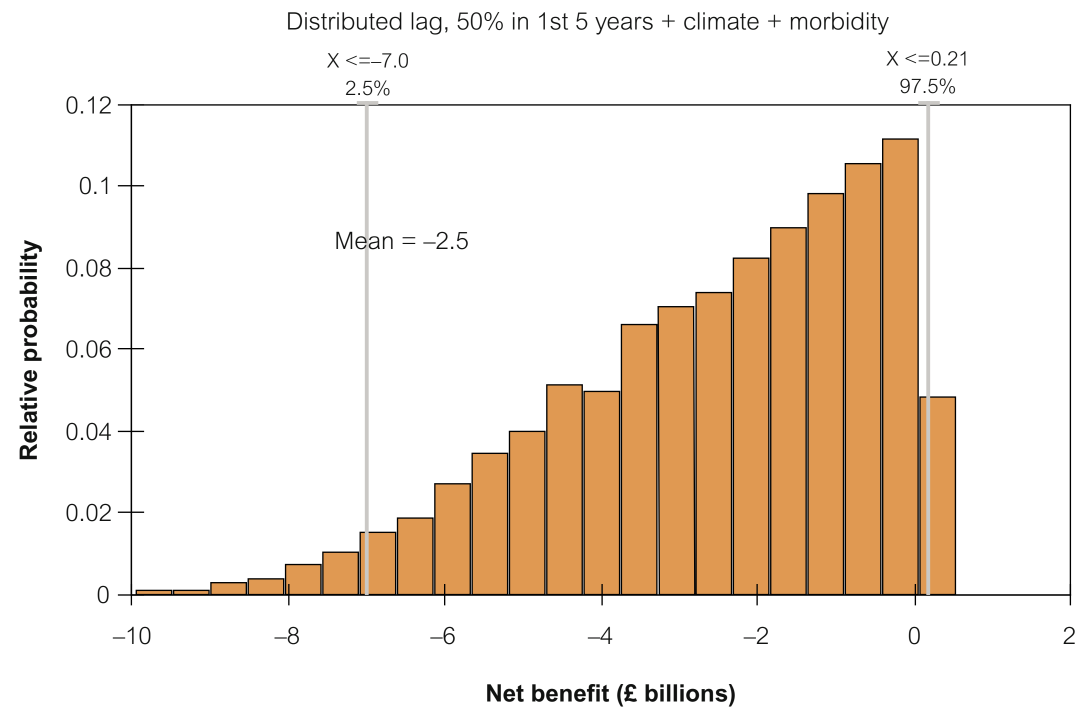


Figure 7.29

Annualised net benefits of Measure R, no lag for mortality impacts with climate benefits and CAFE morbidity benefits added, Annual present value £ billion



Measure B: Benefits

Figure 7.30

Annualised benefits of Measure B, 40 year lag for mortality impacts.
Annual present value £ billion

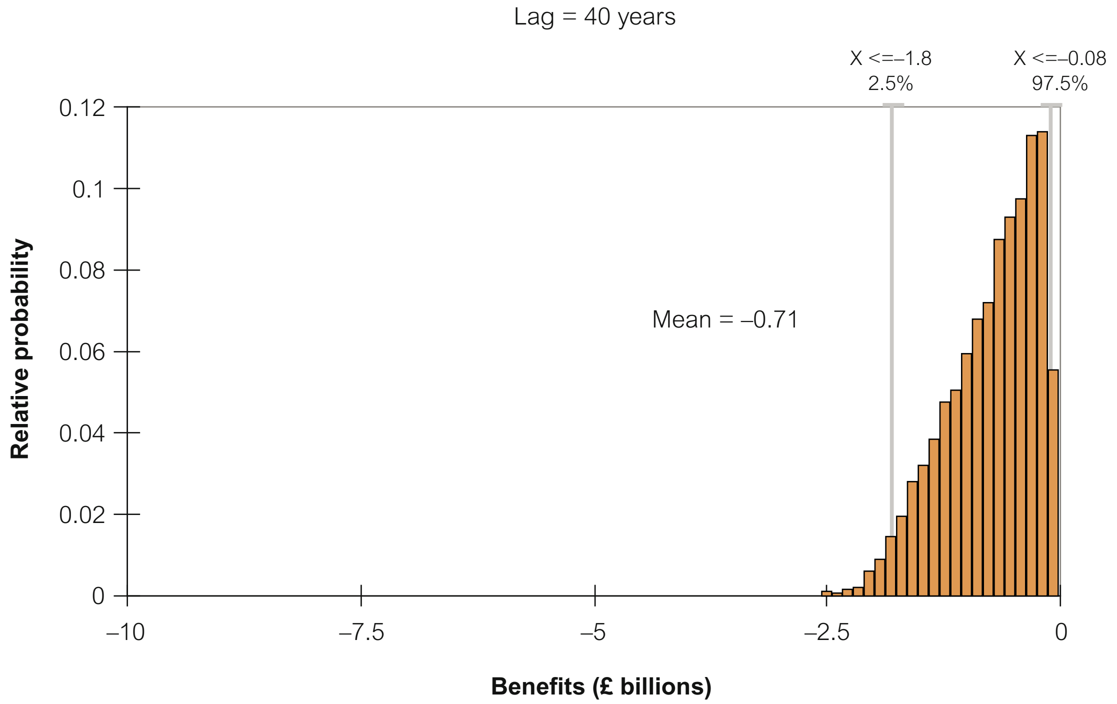


Figure 7.31

Annualised benefits of Measure B, lag for mortality impacts distributed over 40 years with 30% coming in the first 5 years. Annual present value £ billion

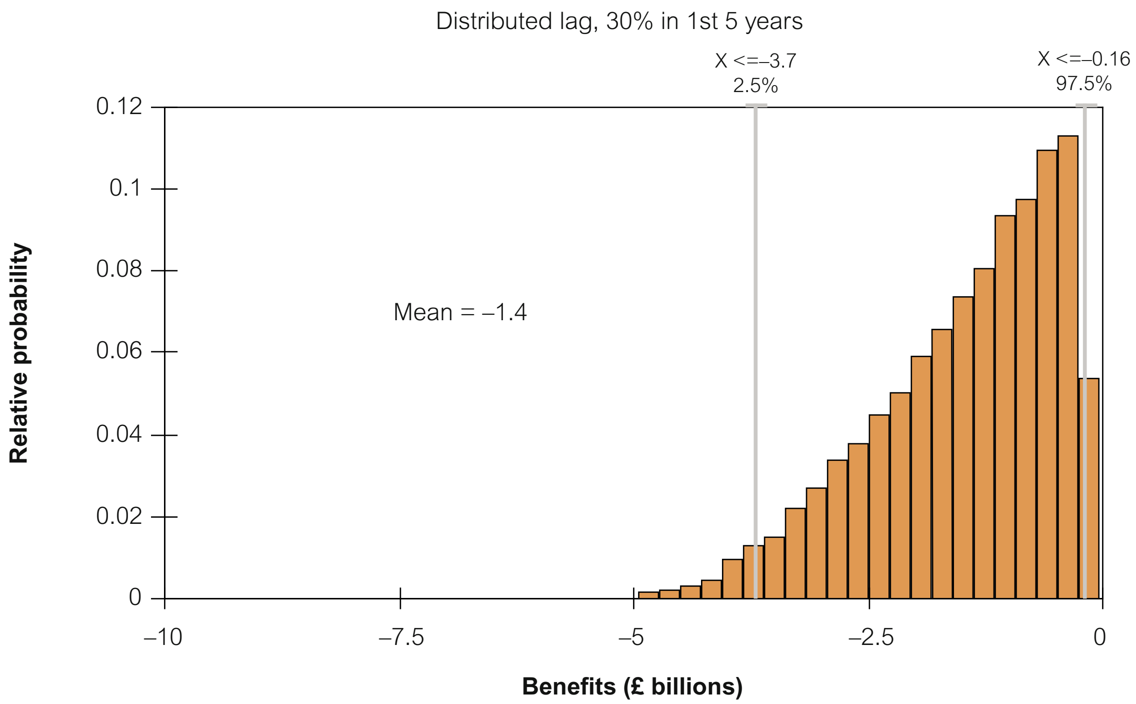


Figure 7.32

Annualised benefits of Measure B, lag for mortality impacts distributed over 40 years with 50% coming in the first 5 years. Annual present value £ billion

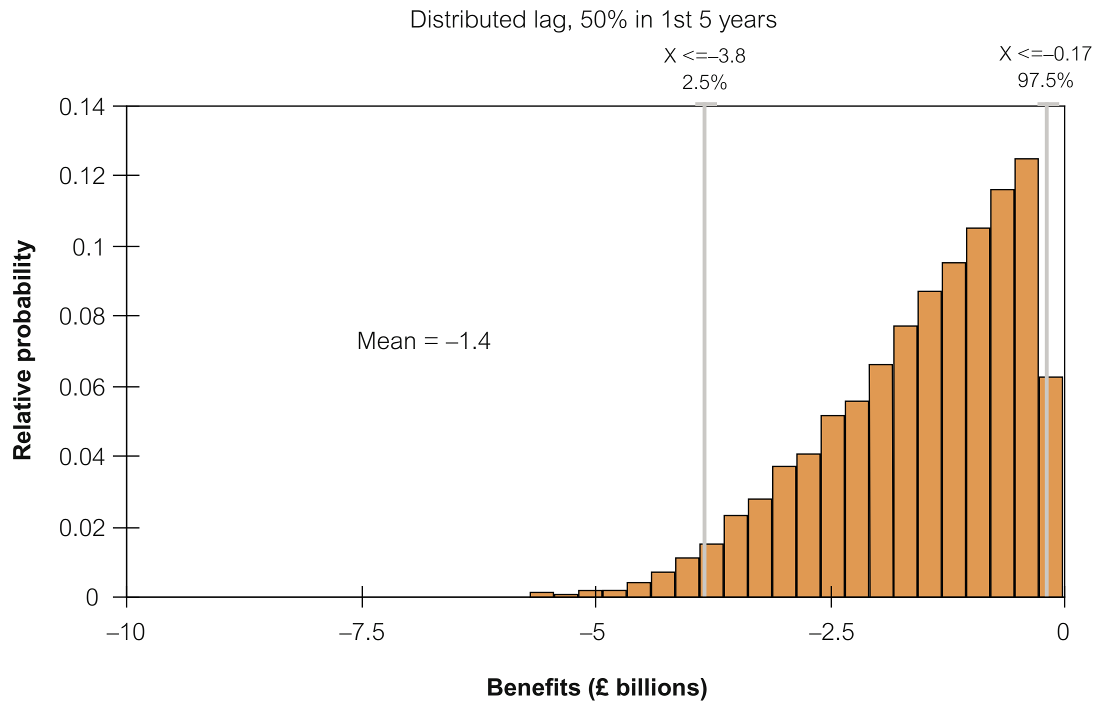


Figure 7.33

Annualised benefits of Measure B, no lag for mortality impacts. Annual present value £ billion

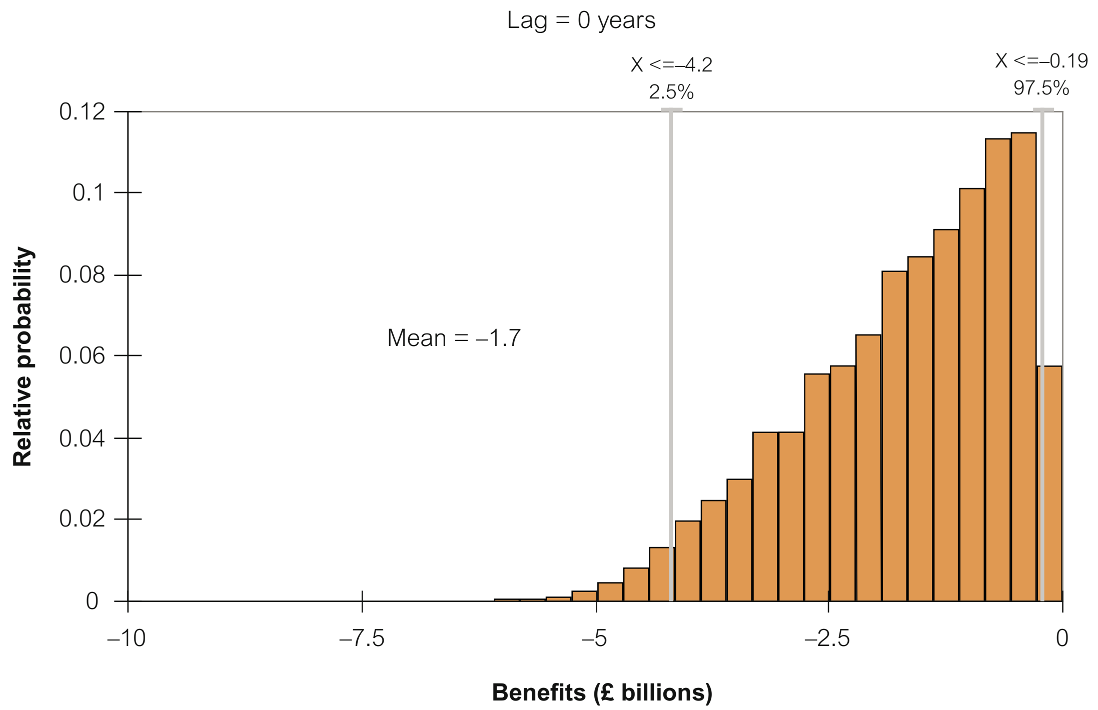


Figure 7.34

Annualised benefits of Measure B, lag for mortality impacts distributed over 40 years with 30% coming in the first 5 years with climate benefits added. Annual present value £ billion

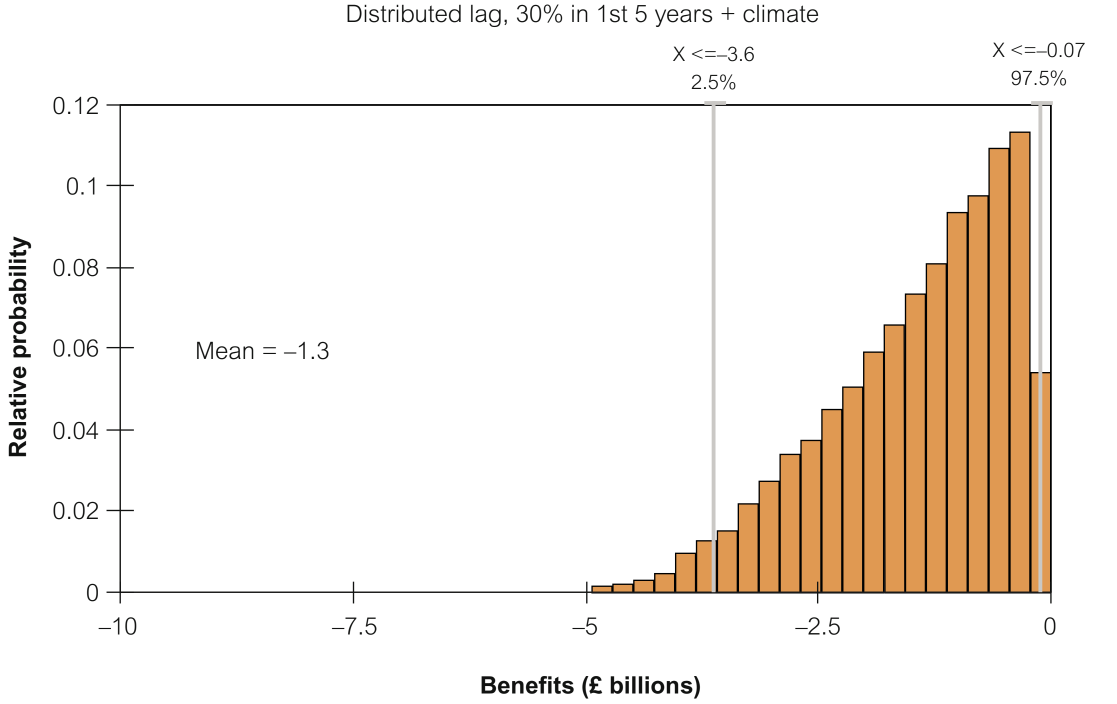


Figure 7.35

Annualised benefits of Measure B, lag for mortality impacts distributed over 40 years with 30% coming in the first 5 years with climate benefits and CAFE morbidity benefits added. Annual present value £ billion

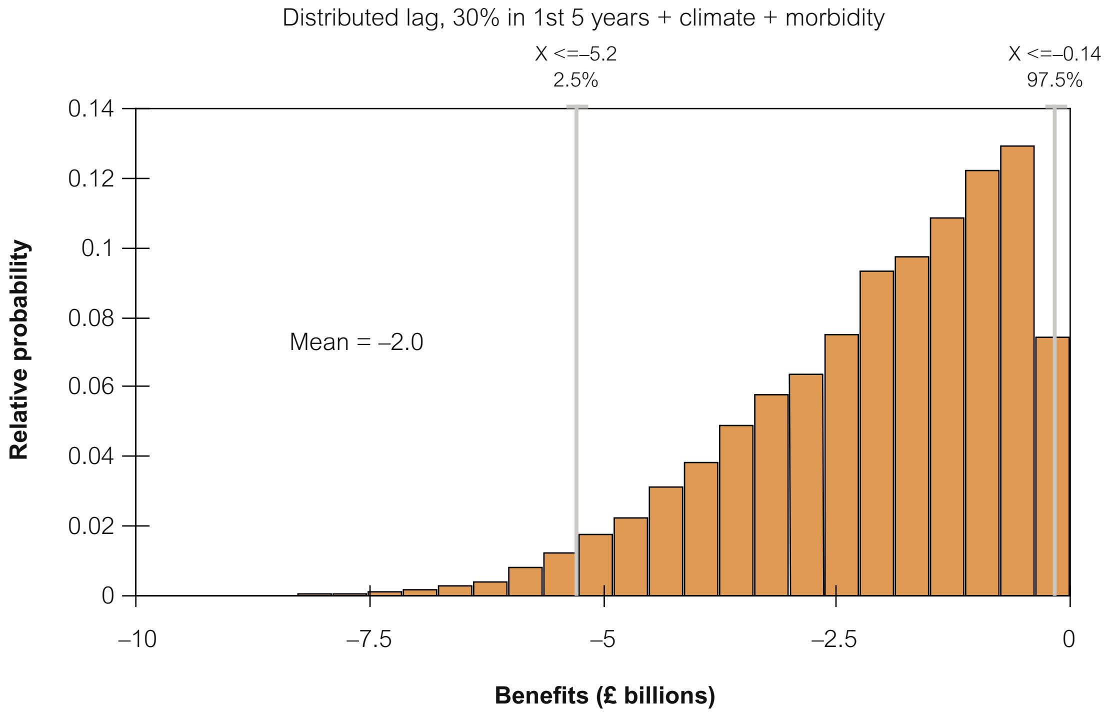


Figure 7.36

Annualised benefits of Measure B, lag for mortality impacts distributed over 40 years with 50% coming in the first 5 years with climate benefits added. Annual present value £ billion

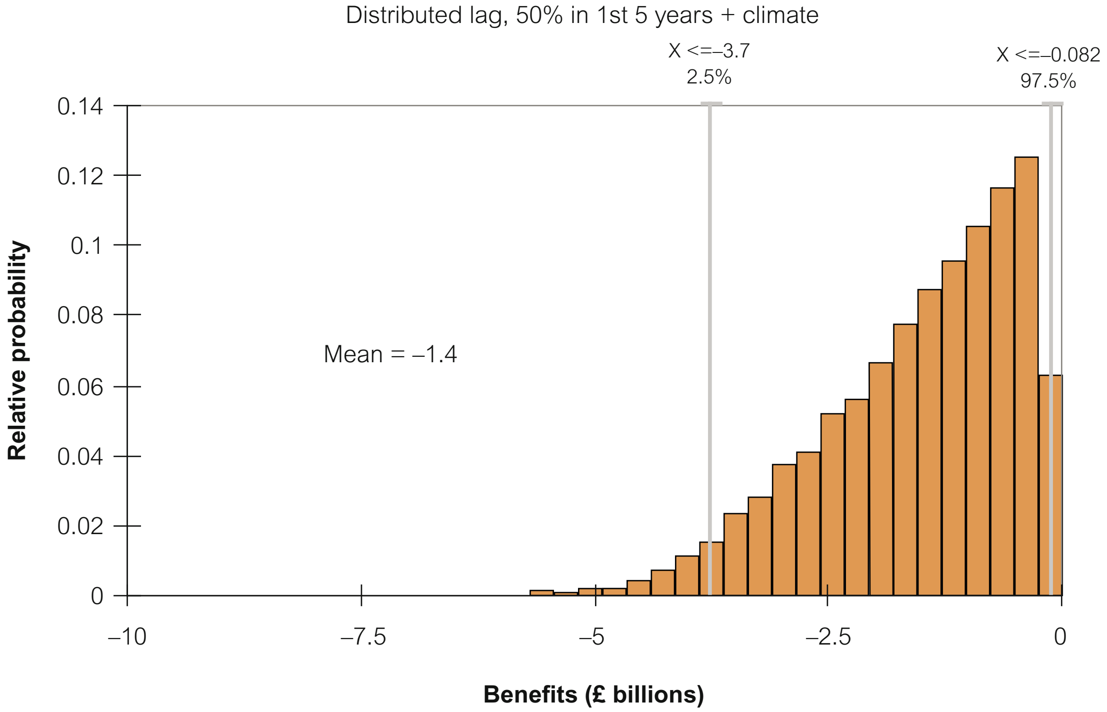
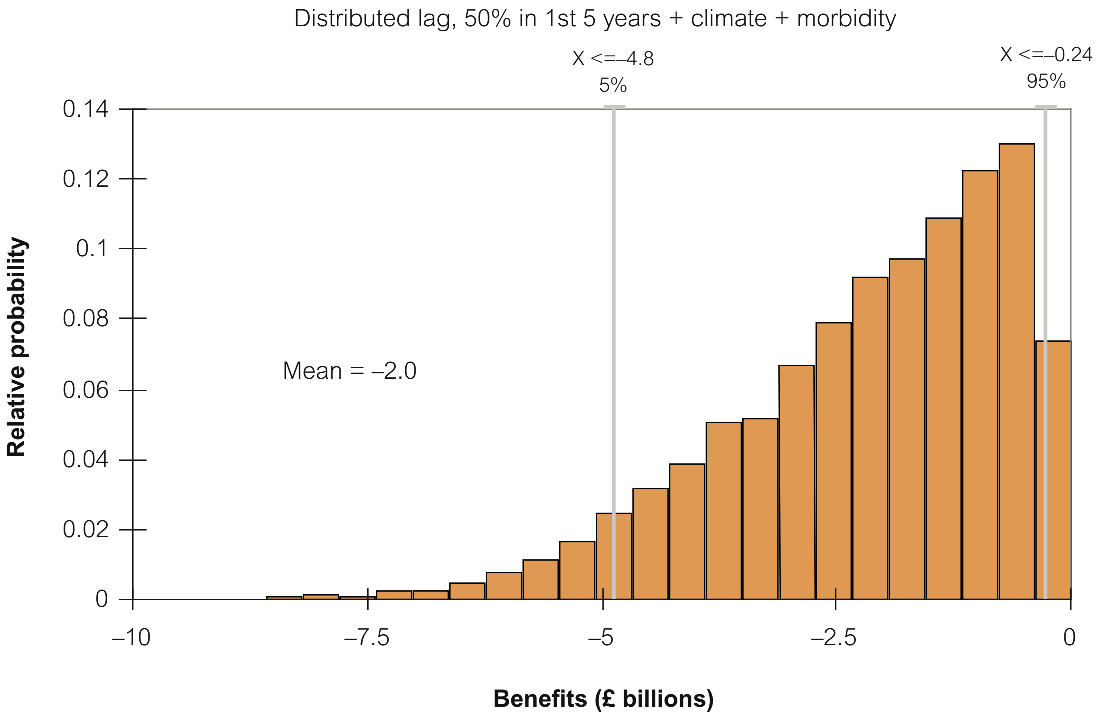


Figure 7.37

Annualised benefits of Measure B, lag for mortality impacts distributed over 40 years with 50% coming in the first 5 years with climate benefits and CAFE morbidity benefits added. Annual present value £ billion



Net benefits for Measure B

Figure 7.38

Annualised net benefits of Measure B, 40 year lag for mortality impacts. Annual present value £ billion

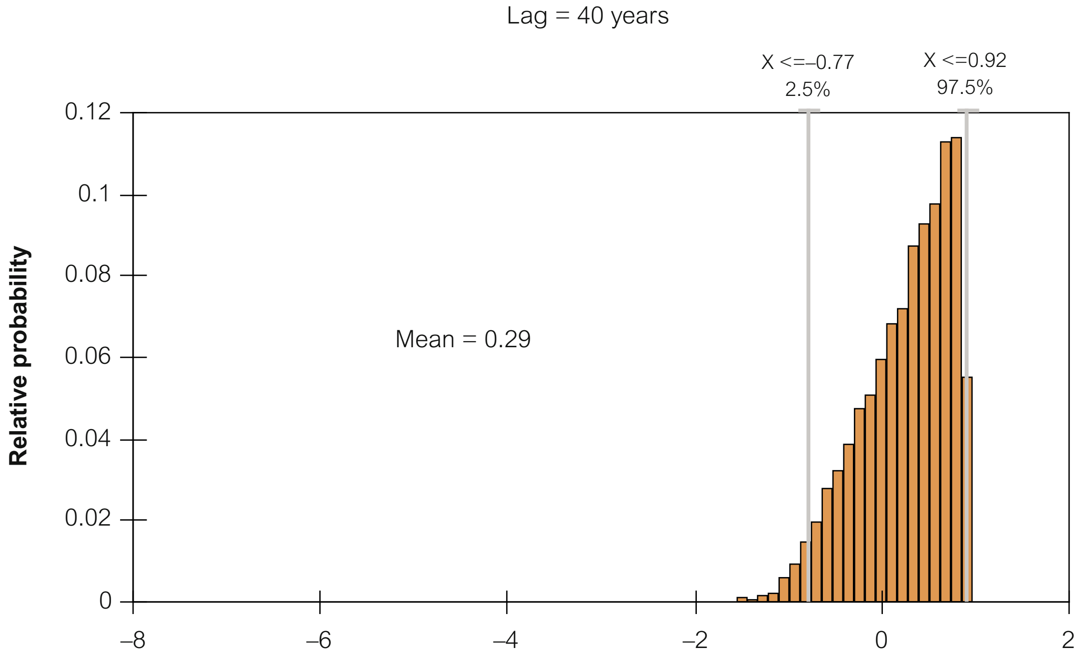


Figure 7.39

Annualised net benefits of Measure B, lag for mortality impacts distributed over 40 years with 30% coming in the first 5 years. Annual present value £ billion

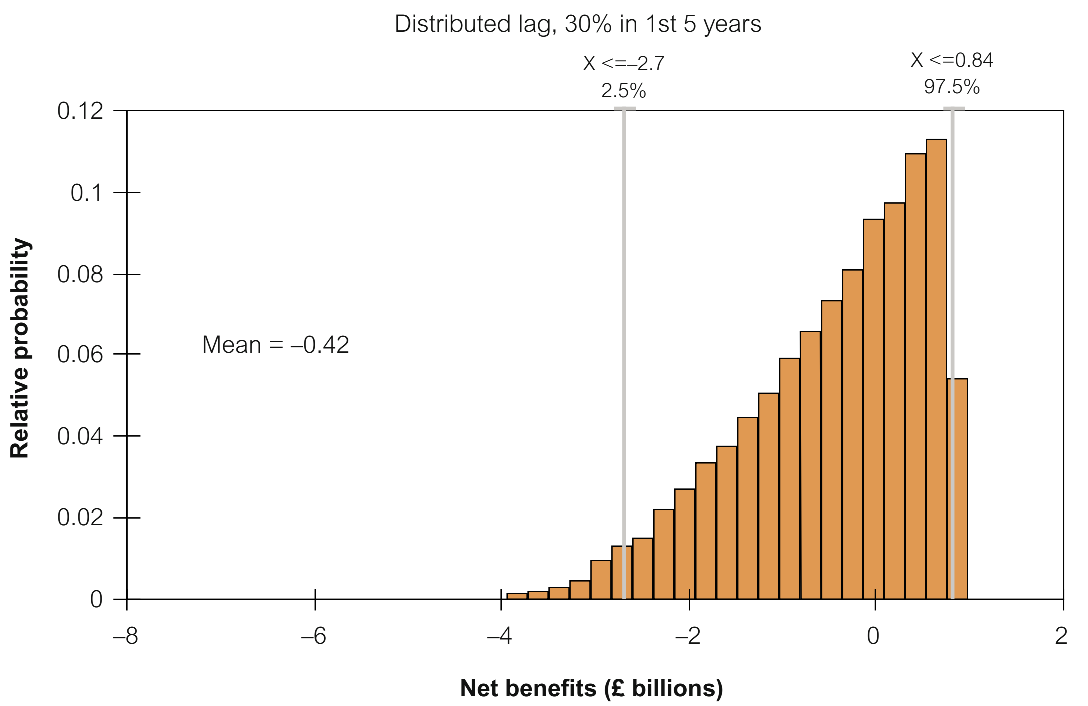


Figure 7.40

Annualised net benefits of Measure B, lag for mortality impacts distributed over 40 years with 50% coming in the first 5 years. Annual present value £ billion

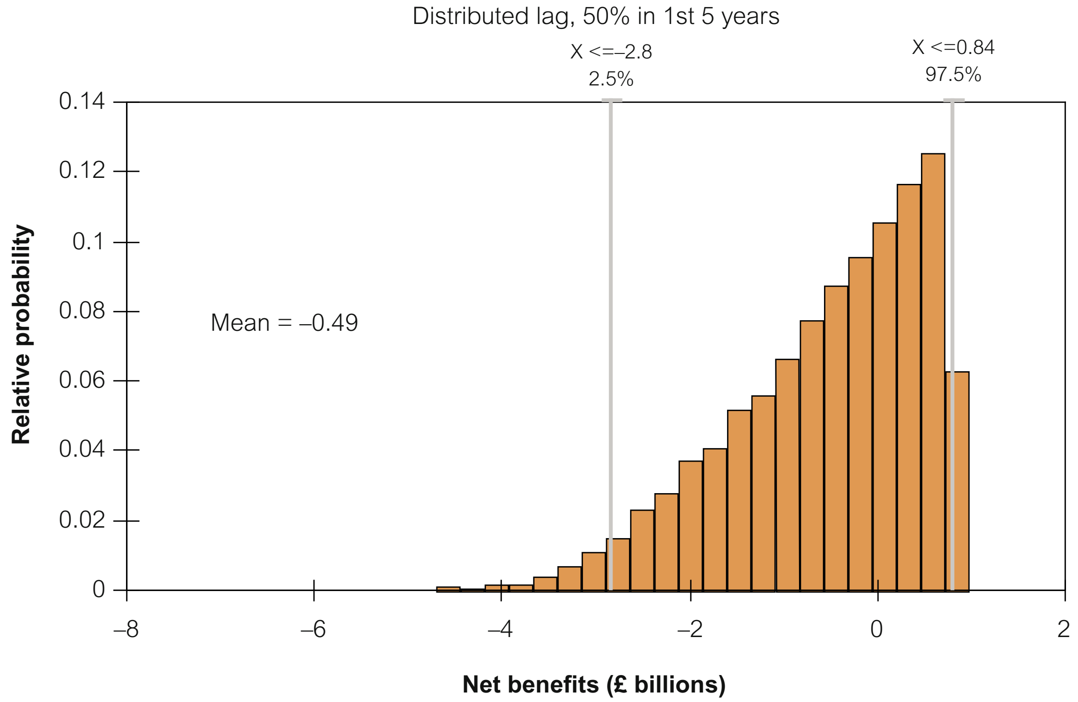


Figure 7.41

Annualised net benefits of Measure B, no lag for mortality impacts. Annual present value £ billion

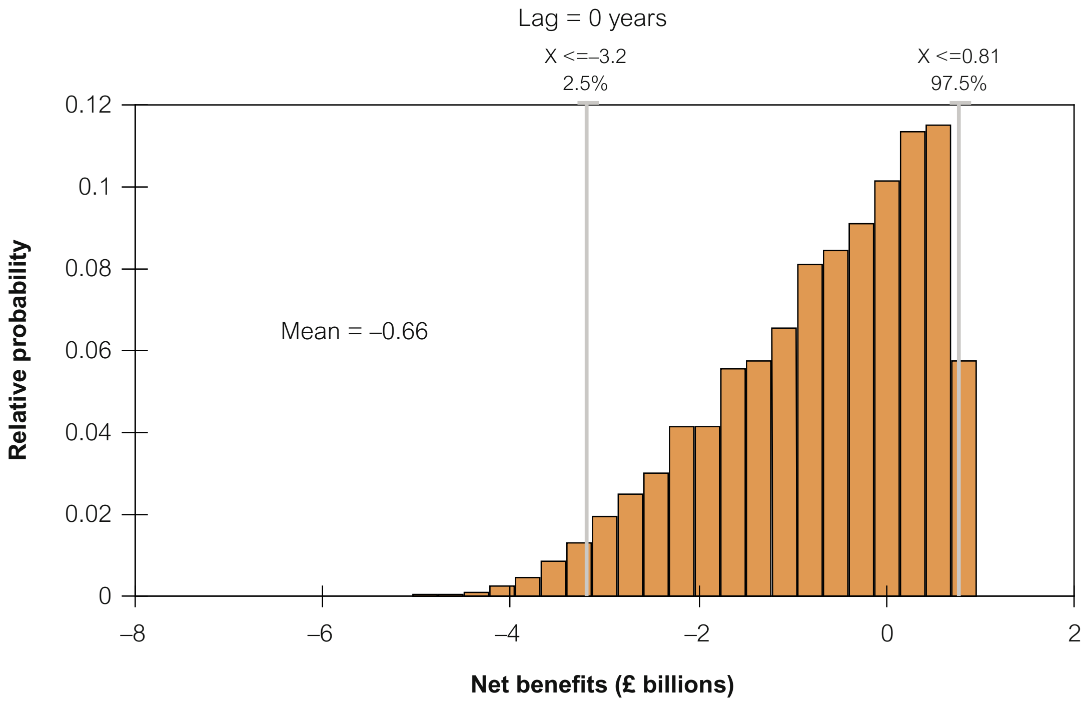


Figure 7.42

Annualised net benefits of Measure B, lag for mortality impacts distributed over 40 years with 30% coming in the first 5 years with climate benefits added. Annual present value £ billion

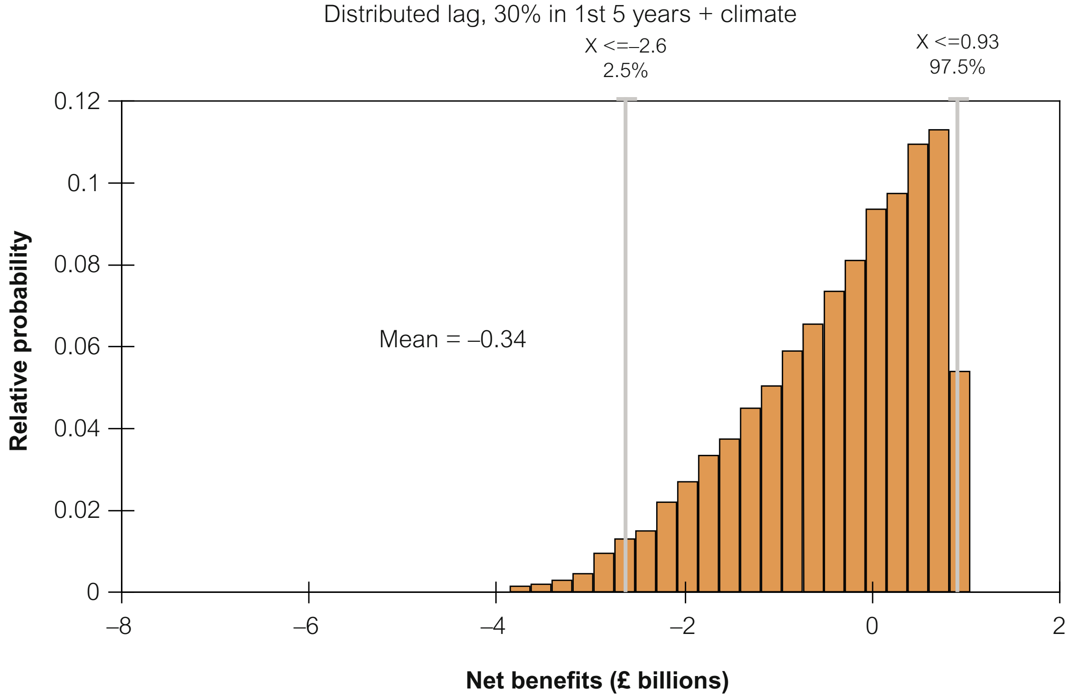


Figure 7.43

Annualised net benefits of Measure B, lag for mortality impacts distributed over 40 years with 30% coming in the first 5 years with climate benefits and CAFE morbidity benefits added. Annual present value £ billion

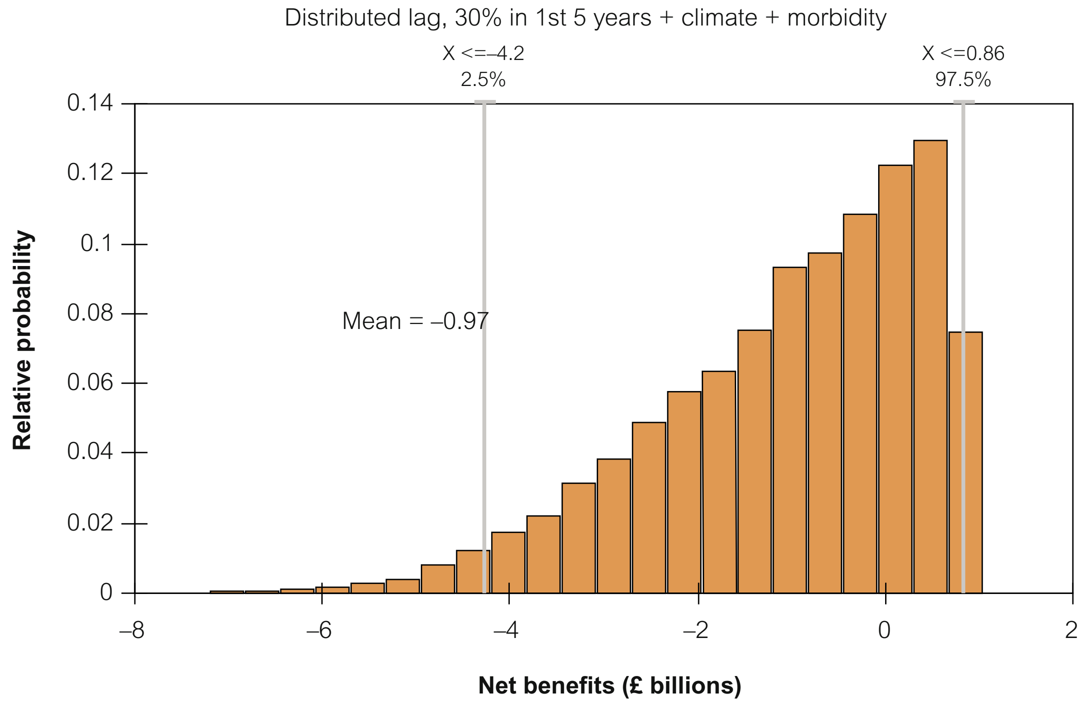


Figure 7.44

Annualised net benefits of Measure B, lag for mortality impacts distributed over 40 years with 50% coming in the first 5 years with climate benefits added. Annual present value £ billion

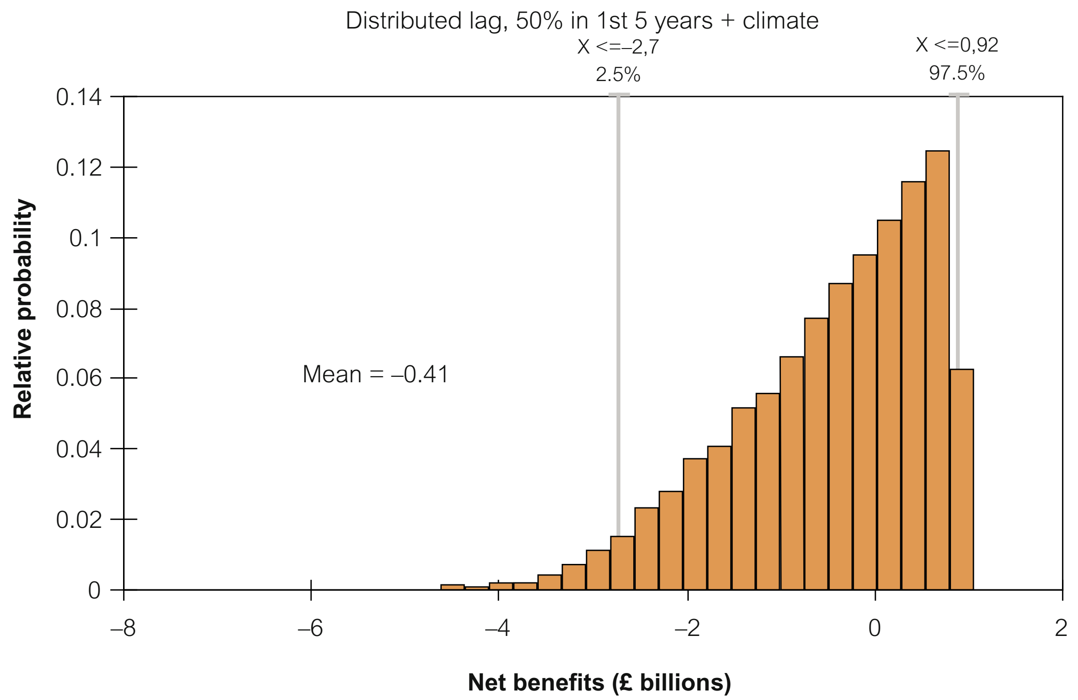
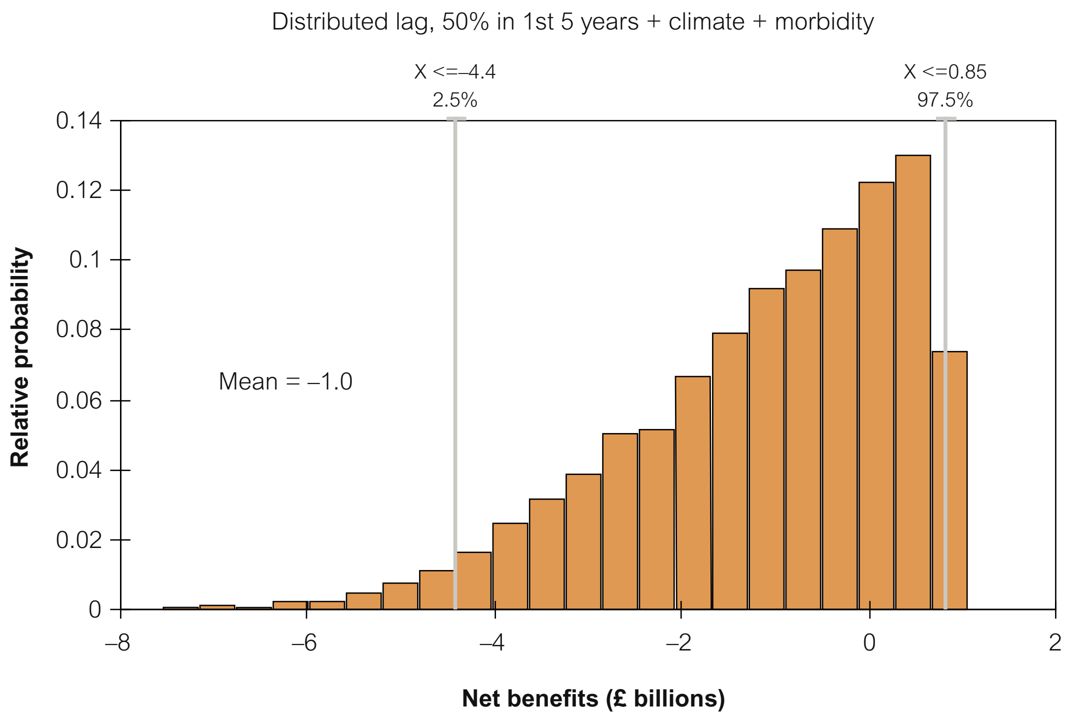


Figure 7.45

Annualised net benefits of Measure B, no lag for mortality impacts with climate benefits and CAFE morbidity benefits added, Annual present value £ billion



Annex 8 – Impacts of recent changes in energy projections

1. This sensitivity analysis uses updated modelling assumptions to check whether any of these new developments would result in any significant change in the cost-benefit analysis results for R.

2. As described in Volume 2, Chapter 1, Section 1.5 of the Air Quality Strategy, this further analysis uses:

- Modelling for the 2004 base year compared with the current 2003 modelling base year. This is to provide estimates for an additional base year with less unusual meteorological conditions;
- A revised source apportionment of regional rural NO_X concentrations to take account of the contributions from shipping and sources in continental Europe;
- The 50% response assumption of secondary PM to changes in the key precursors of SO_2 and NO_2; and
- A more consistent source apportionment of PM_{10} and $PM_{2.5}$ concentrations.

3. Table A8.1 shows the resulting changes in concentrations as a result of using the UEP26, 2004 baseline for measure R

Table A8.1: Changes in concentration by implementing Measure R for the UK UEP26 2004 base year model

Country	Pollutant	Concentration changes relative to the baseline ($\mu g.m^{-3}$)[a]		
		2010	**2015**	**2020**
UK	PM_{10}	(0.261)	(0.678)	(0.995)
	NO_2	(0.215)	(1.051)	(1.851)

[a] Data presented in the table in brackets represents a negative impact
[b] PM_{10} concentrations are presented in $\mu g.m^{-3}$, gravimetric

4. The benefit analysis used the method described in Chapter 2 with any more specific aspects described in Chapter 3 under the component measures C2, E and N. In particular, in addition to the life years calculated over 100 years using the 2020 concentration for R; the difference between life years over a 20 year period from the difference in concentration between A2 and C2 in 2010 was added. (This takes account of the early uptake of Euro standards for measure C2). UEP26 2004 modelling was not performed for A2 and C2, so the '20 year add-on' derived from UEP12 2003 modelling of A2 and C2 was used. Examination of the 2010 concentrations for R using UEP26 2004 modelling (0.261 $\mu g/m^3$ reduction compared with UEP26 2004 baseline) with the equivalent concentration reduction for UEP12 2003 modelling (0.288 $\mu g/m^3$) suggests that the '20-year add-on' may be overestimated by around 10% by using UEP12 2003 modelling. As these additional life years are a small proportion (2-3%) of the total benefits, this small overestimation (0.2-0.3% overall) is acceptable.

5. Table A8.2 illustrates the health impacts generated by the changes in concentrations as outlined in Table A8.1. These are greater than those using UEP12 2003 modelling.

Table A8.2: Quantified impacts of implementing Measure R; UEP26 2004 base year

PM life years saved ('000s) – 6% (2010 – 2109)	PM – RHA (2020 p.a.)	PM – CHA (2020 p.a.)	Carbon ('000s tonnes p.a.) (2020)
2,167 – 4,085	350	350	378

6. These impacts have then been monetised using the methodology described in Chapter 2 and discounted to generate a Present Value (PV), in 2005 prices, of the different impacts. This present value has then been annualised. The monetary values can be seen in Table A8.3 below.

Table A8.3: Annual present value of impacts of implementing Measure R; UEP26 2004 base year

PM life years saved – 6%	PM – RHA	PM – CHA	Carbon	Crops	Buildings & materials
948 – 2,185	1 – 6	1 – 6	36	2	2

7. Using the more precise non-linear scaling (see Section 5.3.3.7 of Chapter 5 for discussion), the life years saved are lower at 2,099 – 3,957 thousand life years. This gives an annual present value for PM life years of £918m – £2,116m.

8. The following table shows the overall cost-benefit analysis for using the alternative energy projections – the UEP12 2003 model which is seen in Chapter 3 of the IGCB report; and the UEP26 2004 model.

Table A8.4: Annual costs and benefits of implementing Measure R; UEP26 2004 base year

	Annual PV of Costs	Annual PV of Benefits	Annual NPV
UEP12			
Linear method	**878 – 885**	**918 – 2,089**	**33 – 1,211**
UEP26			
Linear method	**878 – 885**	**990 – 2,236**	**105 – 1,358**

[a] Numbers in brackets represent negative values.

9. The table above shows that the benefits outweigh the costs of Measure R based on the recommended 6% hazard rate reduction for both the lag and the no-lag scenario. This conclusion is also the same for the alternative energy projections. However, it can be seen that the benefits increase by around 7% – 8% by using the updated UEP26 2004 model (using the linear method). This could be an area for further examination when modelling becomes available for other measures.