

An Economic Analysis to inform the Air Quality Strategy

Volume 3

Updated Third Report of the Interdepartmental Group on Costs and Benefits

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Interdepartmental Group on
Costs and Benefits

July 2007

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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 Addendum¹.

The Air Quality Strategy (AQS) review, published in April 2006, assessed the possible impacts of a range of 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:

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 policies, 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 (SO₂) 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 (PM₁₀), 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 PM₁₀ objective for London, the rest of England, Wales, Scotland and Northern Ireland and the 2005 nitrogen dioxide (NO₂) 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 SO₂, 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, SO₂ 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 2006⁷ 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 median⁸ 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

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 12.5th and 87.5th percentiles of the whole distribution. Department of Health (2007).

Book⁹ 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 (O₃) on crop yields, material damage from SO₂ 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.

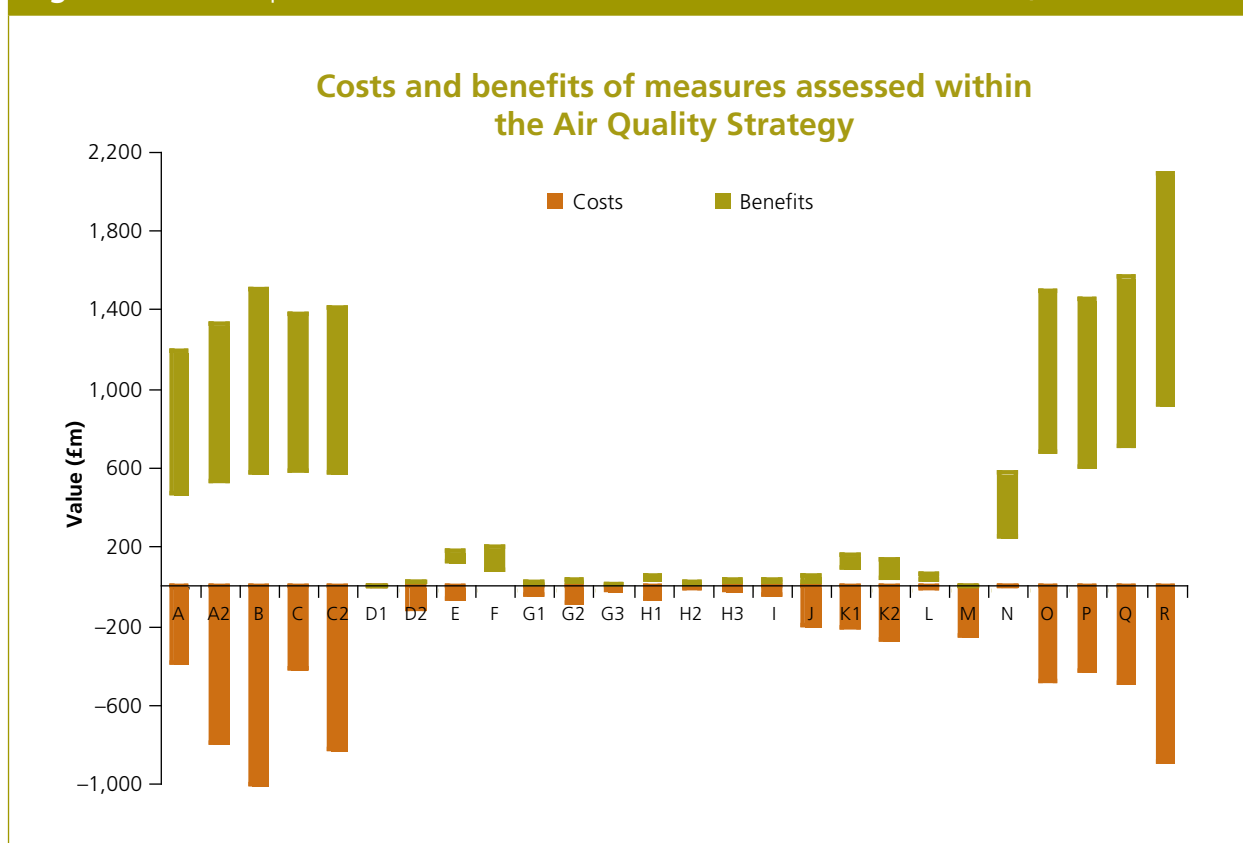
⁹ 'The Green Book: Appraisal and Evaluation in Central Government', HM Treasury (2003).

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/VI standards based on Measure A (Euro low)
C2 (Early Euro revised)	Incentivising early uptake of Euro 5/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

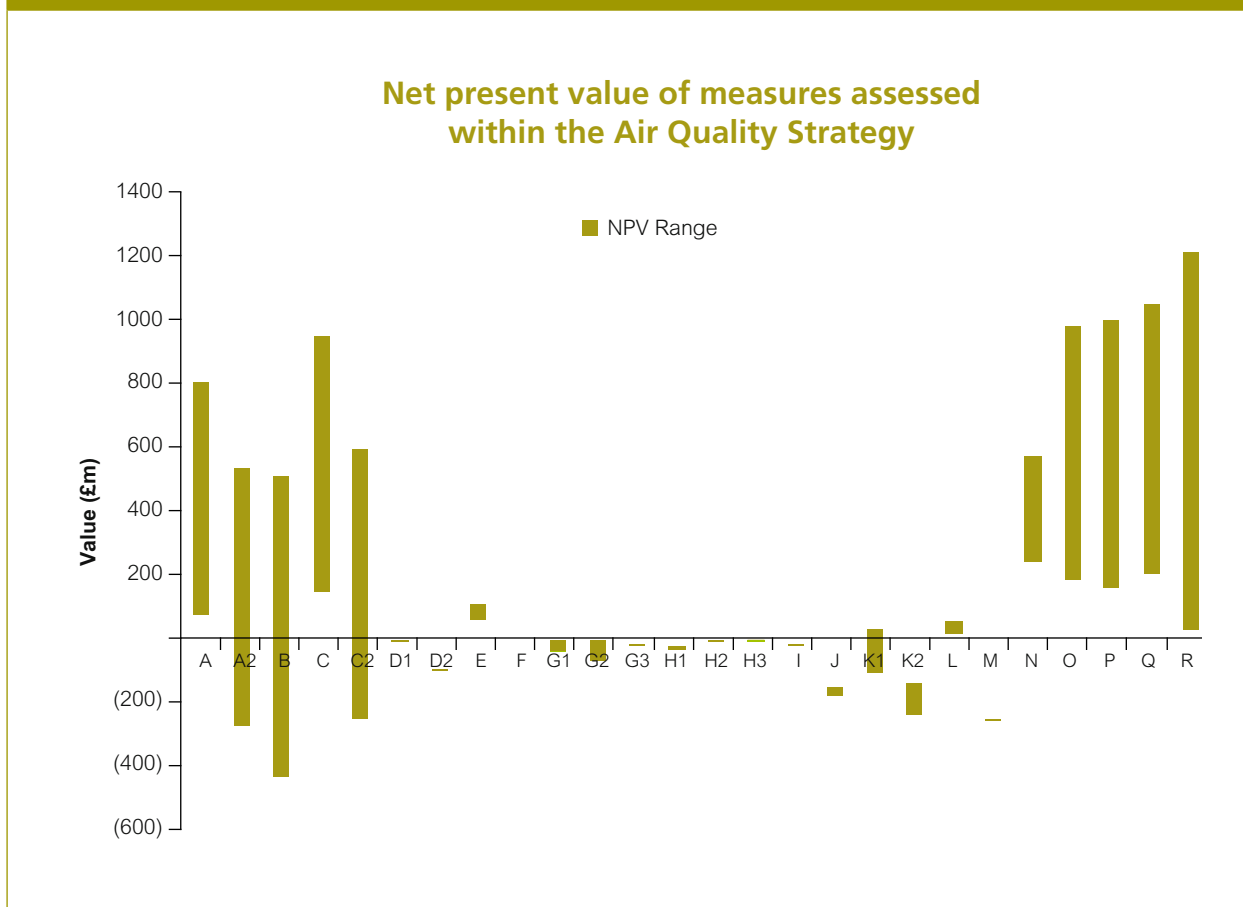
The costs and benefits of the policy measures are shown graphically in Figure E.1. This allows for measures that have the greatest potential benefits, but also higher costs, such as Measure B, to be more easily identified. The benefits are presented as a range, largely driven by the differing assumptions 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 $10\mu\text{g}\cdot\text{m}^{-3}$) with the 40 year lag and the upper bound represents the PV of benefits at the 6% (per $10\mu\text{g}\cdot\text{m}^{-3}$) 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 AQ5



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 $10\mu\text{g}\cdot\text{m}^{-3}$) change in hazard rate with the 40 year lag and the upper bound represents the NPV at the 6% (per $10\mu\text{g}\cdot\text{m}^{-3}$) 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 NO₂ 40µg.m⁻³ annual mean,¹⁰ PM₁₀ <31.5µg.⁻³ and <20µg.⁻³ annual mean objectives for England, Wales and Northern Ireland, excluding London and Scotland.¹¹ The PM₁₀ <31.5 µg.⁻³ objective is seen as equivalent to the PM₁₀ 24 hour mean objective that is used hereon in.

In terms of roadside exceedences of the NO₂ 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 PM₁₀ <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 PM₁₀ 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 PM₁₀ 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.

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 PM₁₀ 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 (km²) 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.

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 NO₂ and PM₁₀ 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, NO₂, PM₁₀ and O₃. 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 NO₂ 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 PM₁₀, 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 PM₁₀ concentrations in the baseline and additional measures will be lower than estimated. Consequently there is a real risk that future concentrations of PM₁₀ 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 $\mu\text{g}\cdot\text{m}^{-3}$ $\text{PM}_{2.5}$ with 0.6% the most likely. These alternative reductions in hazard rate per $\mu\text{g}\cdot\text{m}^{-3}$ $\text{PM}_{2.5}$ 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 $\mu\text{g}\cdot\text{m}^{-3}$ $\text{PM}_{2.5}$ as the values when assuming a 0.6% per $\mu\text{g}\cdot\text{m}^{-3}$ 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 $\text{PM}_{2.5}$ mixture in general and with sulphates specifically. Nonetheless, there is a view, particularly from toxicology studies, that within the general $\text{PM}_{2.5}$ mixture, primary particles are relatively more toxic (per $\mu\text{g}\cdot\text{m}^{-3}$), 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 $\text{PM}_{2.5}$ 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 $\mu\text{g.m}^{-3}$ 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 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 $\mu\text{g.m}^{-3}$ 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)	Not modelled	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.