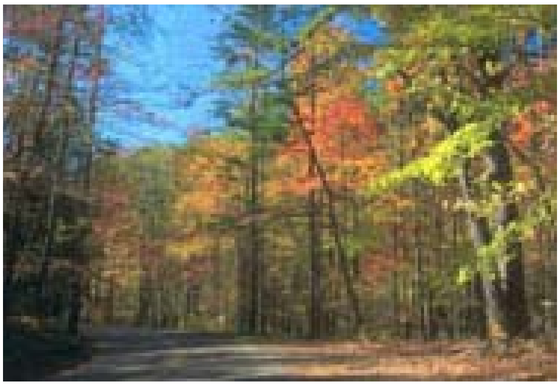
ED50232

An Evaluation of the Air Quality Strategy





Final Report to Defra

December 2004

AEA TECHNOLOGY
ENVIRONMENT

Title	An Evaluation of the Air Quality Strategy
Customer	DEFRA
Customer reference	
Confidentiality, copyright and reproduction	
File reference	
Report number	ED50232
Report status	Issue 4

Paul Watkiss
Building 154
Harwell Laboratory
Didcot
Oxon
OX11 0RA
Telephone 0870 190 6592
Facsimile 0870 190 6327
paul.watkiss@aeat.co.uk

AEA Technology is the trading name of AEA Technology plc
AEA Technology is certificated to BS EN ISO9001:(1994)

	Name	Signature	Date
Author			
Reviewed by	Paul Watkiss		
Approved by	Paul Watkiss		

Research on behalf of Defra by AEA Technology Environment, EMRC, the Institute of Occupational Medicine and Metroeconomica

November 2004.

Authors: Paul Watkiss, Sarah Baggot, Tony Bush, Sam Cross, Justin Goodwin, Mike Holland, Fintan Hurley, Alistair Hunt, Gywn Jones, Sujith Kollamthodi, Tim Murrells, John Stedman and Keith Vincent

Contact Details:

Paul Watkiss
AEA Technology Environment
UK
Telephone (+44) 0870-190-6592
paul.watkiss@aeat.co.uk

Disclaimer:
We would like to thank Defra and in particular the Air Quality Evaluation Steering Group for their input and guidance for this study. We also would like to thank other organisations and individuals that have provided input or contributions, including the peer reviewer, Professor Stephen Smith at University College London. Whilst we acknowledge the contribution made to the study, the results and conclusions presented do not necessarily represent the views of any of these organisations or individuals.

Glossary

Appraisal. Analysis of policy before implementation

B[a]P. benzo[a]pyrene

CO. Carbon monoxide. An air pollutant primarily associated with road transport.

CO_2. Carbon dioxide. A greenhouse gas.

COMEAP. UK Department of Health's Committee on the Medical Effects of Air Pollutants.

CNG. Compressed natural gas. An alternative transport fuel.

CCS. Central London Congestion Charging Scheme. In the text this refers to the area consistent with the CCS.

CRT. Continuously Regenerating Traps. A type of Diesel Particulate Filter.

DEFRA. Department for Environment, Food and Rural Affairs.

DfT. Department for Transport.

DPF. Diesel Particulate Filter.

EAHEAP. Economic Appraisal of the Health Effects of Air Pollution, Department of Health Ad-Hoc Group on the Economic Appraisal of the Health Effects of Air Pollution

EC. European Commission.

EGR. Exhaust Gas Re-circulation.

ESI. Electricity Supply Industry.

EU. European Union.

Euro (1-5). European Commission emission standard legislation, relating to Euro standards I to V.

Evaluation. Analysis of a policy after implementation (ex post).

Ex Ante. Before implementation, as before the introduction of a policy (appraisal).

Ex post. After implementation, as in after the introduction of a policy.

FGD. Flue Gas Desulphurisation

HGV. Heavy Goods Vehicles, i.e. lorries. In the text, this refers to vehicles >3.5 tonnes.

IGCB. Interdepartmental Group on Costs and Benefits.

IOM, generally referring in the text to the work by the Institute of Occupational Medicine for the Scottish Executive, which used a higher exposure-response function for the analysis of chronic mortality impacts from air pollution.

IPC. Integrated Pollution Control.

LEZ. Low Emission Zone.

LGV. Light Goods Vehicles. Light commercial vehicles such as vans.

LNG. Liquefied Natural Gas. An alternative transport fuel.

LPG. Liquefied Petroleum Gas. An alternative transport fuel.

LDV. Light duty vehicles = light goods vehicles and cars.

NFFO. Non-Fossil Fuel Obligation.

NO. Nitric oxide.

NOx. Oxides of nitrogen (includes NO and NO_2).

NO_2. Nitrogen dioxide.

Pre-Euro. Vehicle made before the introduction of European legislation on emission limits for new vehicles was introduced.

PM_{10}. Particulate matter less than 10µm aerodynamic diameter.

RO/ROCs. Renewables Obligation/ Renewables Obligation Certificates

RPC. Reduced Pollution Certificate. The RPC scheme enables vehicles with modifications or particulate traps fitted to reduce particulate matter to benefit from reduced VED.

SO_2. Sulphur dioxide.

SCR. Selective Catalytic Reduction.

T*f*L. Transport for London.

TWC. Three-way catalyst.

UNECE. United Nations Economic Commission for Europe Convention

VED. Vehicle Excise Duty.

VOC. Volatile Organic Compounds.

Executive Summary

Government policies need to be evaluated, in order to inform the ongoing development of future policy. This study, '*An Evaluation of the Air Quality Strategy'*, has evaluated selected air quality policies over a period of major change, from 1990 onwards, and assessed their cost effectiveness in achieving air quality improvements. The study has also assessed the costs and benefits of these policies, to provide information on which policies have been successful and which have not. Finally, the study has evaluated how closely the actual out-turns of policies match the anticipated effect, to help inform future appraisals.

The study has not considered all air quality policies, in all sectors. Tackling all of these would have been too broad a remit. Instead the study has evaluated the two most important sectors - **road transport** and **electricity generation**. The consideration of other sectors, particularly industry and the domestic sector, is one of the priorities identified for future research. Within the two sectors, the evaluation has focused on specific legislative policies, rather than broader measures. It has also excluded specific policies aimed at reducing CO_2, as these have been evaluated in other studies.

The study has assessed the estimated out-turn that would have occurred in the absence of the policies. This is referred to as the 'no abatement' scenario (also called the 'without policies' or 'counterfactual' scenario). For each sector, the study has then evaluated the estimated effect of policies against this 'no abatement' scenario in terms of:

- The emissions reductions achieved by the policies;
- The progress towards the UK/European Union (EU) air quality objectives/limit values;
- The benefits of the policies in terms of physical effects and monetary valuation;
- The costs of policies, as anticipated in Government appraisal before the legislation was implemented ('*ex-ante*'), and the actual cost out-turn after introduction ('*ex-post*').

The results of the analysis are presented for the **evaluation period** from 1990 – 2001. However, the benefits of the existing policies extend beyond this period, and so we have extended the analysis over a **projected period** from 2002 – 2010[1].

For the **road transport** sector, the study has primarily assessed European command and control policies affecting vehicle emissions and fuel quality, but has also included national initiatives using duty differentials. The policies include unleaded petrol, successive controls on the sulphur content of diesel and petrol, and successive Euro standards (from Euro I to IV). These policies have been introduced sequentially through the study period.

For the **electricity supply industry** (ESI), the study has considered a much wider number of policies, including European command and control policies, international protocols, national environmental policy and market-based instruments (e.g. renewable subsidies). These policies do not follow a sequential order. Moreover, since 1990, the UK electricity sector has undergone a radical restructuring and liberalisation, which has had a major role in reducing air pollution and helping to meet environmental legislation and commitments. The combination of energy and environmental policy have led to a number of 'convergences', which have led to the actual out-turn seen in the sector, for example in respect to increased use of natural gas as a fuel. The study has evaluated the costs and benefits of all air quality improvements in the ESI, and then assessed the proportion of these that could be allocated to air quality policy.

[1] Note all counterfactual scenarios are based on 1990 conditions, extrapolated forward over time. For the 2002 – 2010 period, we have not re-assessed the baseline conditions in 2001. We stress that the underlying analysis for future projections was consistent with the best available information at the time of the study, and was based on the 2001 NAEI projections. The NAEI projections have been subsequently revised for both road transport sector and the ESI.

The results of the study are presented below[2], for each of the key evaluation questions raised. The benefits are presented relative to the expected out-turn in that year, rather than the benefits relative to 1990 conditions: for example, the benefits in 2001 are the difference between the actual out-turn in 2001 and the estimated out-turn 'without policies' in 2001. We stress that the expected out-turn 'without policies' has been estimated for each of two sectors separately.[3] Where appropriate, the results from the two sectors are combined to give an aggregated analysis. Note the analysis assumes that all current policies in other sectors are in place.

Cost-Effectiveness of the Policies

The study has first considered whether '*the policies have been cost effective in achieving air quality improvements and consequent health and other benefits'*. We conclude that the policies in both sectors have led to major emissions reductions, when compared to the expected out-turn without the policies in place. There has also been a dramatic improvement in air quality, which has enabled significant progress towards the UK and European air quality objectives. Finally, there have been extremely large benefits in reducing the health and environmental impacts of air pollution. The emissions reductions in the two sectors are shown below.

Annual emissions reductions in the two sectors, relative to the expected out-turn 'without policies'. 1) Achieved in the evaluation period (to 2001) and 2) projected (by 2010).

	Reduction relative to expected out-turn – Road Transport *	Reduction relative to expected out-turn – ESI *
1) Evaluation Period (in 2001)		
SO_2 kilo-tonnes (% reduction)	77 (96%)	2430 (77%)
NO_X kilo-tonnes (% reduction)	448 (36%)	530 (58%)
PM_{10} kilo-tonnes (% reduction)	28 (48%)	64 (78%)
2) Expected (by 2010)		
SO_2 kilo-tonnes (% reduction)	86 (96%)	3094 (93%)
NO_X kilo-tonnes (% reduction)	919 (69%)	662 (69%)
PM_{10} kilo-tonnes (% reduction)	58 (76%)	80 (93%)

* All of the emissions reductions for the road transport sector can be attributed to air quality policy. The reductions shown for the ESI represents the total reduction seen in the sector seen over the period, however, not all of these can be directly attributed to air quality policy. For the ESI, we estimate between 38 to 100 % of the SO_2 emissions reductions, 34 to 100% of the NO_X emissions reductions, and 46 to 100% of the PM_{10} emissions reductions can be attributed to air pollution policy.

- For the **road transport** sector, the policies implemented have led to an almost complete removal in lead emissions, a very large reduction (96%) in SO_2 emissions, and a 35 to 55% reduction for the other main pollutants (NO_X, primary PM_{10}, CO, VOC) within the evaluation period (to the end of 2001), when compared to the expected out-turn 'without policies'. These emissions reductions are projected to increase in future years, so that by 2010, there is a 69% reduction in NO_X and a 76% reduction in primary PM_{10} emissions, when compared to the 'without policies' scenario. All of these emissions reductions can be attributed to air quality policies.
- For the **electricity** sector, there has been a very large reduction in the main air pollutants in the evaluation period (to 2001), with a 77% reduction in SO_2, a 58% reduction in NO_X and a 78% reduction in primary PM_{10} emissions, compared to the expected out-turn 'without policies'. The reductions are projected to increase in future years, with a 93% reduction in SO_2, a 69% reduction in NO_X, and a 93% PM_{10} emissions by 2010, compared to the 'without policies' scenario.

[2] Note no inferences should be drawn from this study about the relative effectiveness of instruments or policies beyond those explicitly covered in the study (or their potential application in other sectors).
[3] For both sectors, the modelling of the 'without policies' out-turn has not considered the effect of potential price changes on demand. While this affects both sectors, we believe such effects would be more important for the ESI.

- There has been a larger absolute reduction in emissions (i.e. in tonnes) in the ESI than in the road transport sector. However, not all of the emission reductions in the ESI can be attributed to air quality policy. We estimate that between 38 to 100 % of the SO_2 emissions reductions, 34 to 100% of the NO_X emissions reductions, and 46 to 100% of the PM_{10} emissions reductions can be attributed to air pollution policy. The range reflects the difficulty in allocating emissions reductions to air pollution policies or other policies[4].

The policies have also been extremely successful in progress towards the UK and EU air quality targets (objectives/limit values), which have implementation dates of 2004/5 and 2010. Interestingly, the policies in the two sectors have been complementary, i.e. it has been necessary to have action in both sectors to enable significant progress towards the major air quality objectives:

- The key benefit of the **road transport sector** policies has been the reduction of NO_2 concentrations, and progress towards the NO_2 objectives. All of these benefits can be attributed to air quality policies. While there have been reductions in NO_X emissions from the ESI, these will have much less effect in reducing NO_2 concentrations in the areas that exceed the objective.
- The key benefit of lower **ESI** emissions has been the reduction in SO_2 concentrations, and progress towards the SO_2 objectives.
- Both sectors have had benefits in reducing PM_{10} concentrations. The policies in the road transport sector have been extremely successful in enabling progress towards the PM_{10} objective by reducing primary PM_{10} emissions. The emission reductions seen in the ESI has been extremely effective in reducing secondary particulate concentrations (PM_{10}) from SO_2 (sulphates). Without the emission reductions in the ESI, the benefits of the policies in the road transport sector would not be sufficient to prevent wide-scale exceedences of the stricter PM_{10} objectives.

The progress towards the objectives will reduce the population that is exposed to air pollution concentrations above the air quality objectives in future years (note these objectives were set at levels to protect human health and the environment). For example:

- Without the policies introduced in the **road transport** sector, the population that would be exposed to annual mean concentrations > 40µg/m^3 NO_2 has been estimated at 17 million people in the UK in 2010 (i.e. under the 'without policies' scenario). With existing road transport policies in place, this is now projected to fall to 0.36 million people by 2010, a 98% reduction on the 'no abatement' out-turn. All of this benefit can be attributed directly to air quality policies.
- Without the emission reductions achieved in the **electricity** sector, the population that would be exposed to 24 hour mean concentrations > 125µg/m^3 µg/m^3 SO_2 has been estimated at 2 million people in the UK in 2004/5. The emission reductions that have occurred in the ESI are projected to reduce all exceedences of the objective level (though not all of the emission reductions achieved in the ESI can be attributed directly to air quality policy).

The reductions in air pollution concentrations have also led to major health benefits. The combined benefit from policies introduced in the road transport sector, plus all air quality reductions seen in the ESI (from air quality and other policies), when compared to the 'without' policies scenario are.

- An estimated <u>annual</u> reduction of 4,225 deaths brought forward and 3,537 respiratory hospital admissions by the end of the evaluation period (by 2001). This is the benefit in the year 2001 with policies in place, compared with the predicted out-turn 'without' policies for that year.
- An estimated <u>annual</u> reduction of 38,990 to 116,971 life years lost by the end of the evaluation period (by 2001)[5]. This is the benefit in the year 2001 with policies in place, compared with the predicted out-turn 'without' policies for that year.

[4] Note for SO_2, the UNECE target mandated a 50% reduction over 1990 levels by 2000. This is consistent with around 70% of the SO_2 emissions reductions seen between the 'without policies' scenario, and the actual policy out-turn.
[5] A range is shown for life years lost (or gained), to reflect different risk factors for 'chronic mortality' effects.

- These benefits are projected to increase significantly in future years, with an annual reduction of 6,587 deaths brought forward and a reduction of 81,601 to 244,803 life years lost each year by 2010. This is the benefit in the year 2010 with policies in place, compared with the predicted out-turn ‘without’ policies for that year.
- These health benefits are dominated by the reduction in PM_{10} concentrations, from reductions in primary PM_{10} directly emitted from vehicles or power plants, but also from secondary particulates formed from the emissions of NO_X and SO_2. However, different pollutants dominate the health benefits in the two sectors.
- For the **road transport** sector, the health benefits primarily arise from reductions in primary PM_{10}. While a similar reduction of primary PM_{10} (in tonnes emitted) has occurred in the ESI over the evaluation period, the primary PM_{10} emission reductions from the road transport sector have had a much greater health benefit because these emissions are released at ground level, often in urban areas with very high population densities.
- For the **electricity** sector, the health benefits primarily arise from the reduction in secondary PM_{10} (i.e. sulphates formed from SO_2 emissions). Indeed, the reduction in sulphates is responsible for the largest improvement in health benefits of any pollutant over the evaluation period. The ESI also leads to some additional health benefits (‘deaths brought forward’ avoided) from the reduction in SO_2 as a gas. This explains the greater proportion of avoided ‘deaths brought forward’ compared to avoided ‘years of life lost’ between the ESI and the road transport sector.
- The health benefits achieved in each sector are shown in the Table below. All of the benefits from the road transport sector can be attributed to air quality policies. We estimate that between 38 and 100% of the benefits in the electricity sector can be directly attributed to air quality policies.

Annual health benefits in the two sectors, relative to the expected out-turn ‘without policies’.
1) Achieved in the evaluation period (to 2001). 2) Projected (by 2010).

Cases avoided each year	Road Transport *	ESI *
1) Evaluation Period (in 2001)		
‘Deaths brought forward’ avoided/yr	500	3,725
Respiratory Hospital Admissions avoided/yr	490	3,047
‘Life years saved’ each year	9,670 (central low) to 29,010 (central high)	29,320 (central low) to 87,961 (central high)
2) Expected (by 2010)		
‘Deaths brought forward’ avoided/yr	1,400	5,187
Respiratory Hospital Admissions avoided/yr	1,370	4,578
‘Life years saved’ each year	26,960 (central low) to 80,880 (central high)	54,641 (central low) to 163,923 (central high)

The reduction in the table is shown as the benefit from the pollution change in the individual year (2001 and 2010) compared to the predicted out-turns ‘without’ policy for each year.

*Note the health benefits above do not include benefits from reductions in ozone. They only include health benefits that occur in the UK. A range is shown for life years gained (‘central low’ to ‘central high’), to reflect the range of different risk factors for ‘chronic mortality’ effects.

Note the health benefits from the two sectors are dominated by different components of the particulate mixture: sulphates from the ESI, nitrates and primary PM from road transport. In the table above, the health impact (causality) of all PM components is treated as equal. However, in the main report we have assigned different levels of confidence to different components. This is presented through uncertainty bands and additional sensitivity analysis to test different toxicities.

All of the health benefits for the road transport sector can be attributed to air quality policy. The benefits shown for ESI represent the total reductions seen in the sector seen over the period. Not all of these can be directly attributed to air quality policy. We estimate that between 38% and 100% of benefits for the ESI could be attributed to air quality policy.

Interestingly, the results show a different pattern of benefits, according to whether results are presented in terms of emissions reductions, pollution concentration reductions, or health benefits. This highlights that for future appraisal and policy, it is important to take account of all these aspects, in order to see the full impact of policy.

The study has not undertaken a comparative analysis of the benefits of the implemented policies against other sectors. This makes a direct evaluation on cost-effectiveness extremely difficult. Nonetheless, from an analysis of the actual 'ex post' costs of the legislation below, we conclude that the policies have been extremely cost-effective, and it is likely that the air quality benefits have been achieved at low or even least-cost.

Costs and Benefits

The study has considered '*what are the costs to the UK economy of policies to reduce air pollution and how do these compare against the benefits of air quality improvements achieved'*. The overall costs and benefits in each of two sectors have been assessed. The study has also assessed the costs and benefits of individual policies.

The economic benefits of **road transport** policies, compared to the 'without policies' scenario, are:

- Annual benefits are estimated at £462 million (central low estimate) to £2,746 million (central high estimate) by the end of the evaluation period (in 2001)[6].
    - By 2010, annual benefits (undiscounted) are projected to rise to £924 million (central low) to £5,338 million (central high).
- Total benefits in the evaluation period (1990 – 2001) are estimated at £2,941 million (central low) to £18,370 million (central high).
    - When the benefits in the entire relevant period of the study (1990 – 2010) are considered, the total discounted benefits rise to an estimated £8,721 million (central low) to £51,510 million (central high).
- Note these total benefits are from emissions in the time period 1990 – 2010 only. They do not include benefits from lower emissions in future years (post 2001 for the evaluation, or post 2010 for the projected analysis) from a move to sustained new pollution levels[7].
- All of these benefits can be attributed to air quality policies. Note the values do not include the effects of road transport emissions on ozone. They also do not include trans-boundary effects (i.e. benefits in Europe from a reduction in UK emissions), or the benefits in the UK from reductions in European emissions from the implementation of this legislation (e.g. from Euro standards) abroad.

These benefits can be compared against the costs of the policies. We stress that there are two sets of cost data that are relevant. The first relates to the estimated costs of policies before implementation (known as '*ex ante'* costs). The second assesses the actual costs of the policies once in place ('*ex post*' costs). For the transport sector, the estimated costs are as follows:

- The total ex ante costs of the policies were estimated at £16,109 million (low) to £22,807 million (high) for the evaluation period (1990-2001), rising to £46,917 million (low) to £67,351 million (high) for the entire period (1990 – 2010). These costs are higher than our central low estimate of benefits above, but broadly similar to our central high estimate of benefits.
- The total ex post costs of the policies are more difficult to estimate accurately. It is clear that they are lower than indicated by the ex ante analysis. We estimate that the cost out-turns of policies in the evaluation period (1990 –2001) could be of the order of £3,000 million. This is similar to the 'central low' estimate of benefits above, and much lower than the 'central high' estimate of benefits. However, a further detailed ex post evaluation is needed to confirm this value.

[6] The values are the benefit in the individual year (2001) compared to the predicted out-turns 'without' policy for that year.
[7] This approach has been used to ensure consistency in comparing the costs and benefits over similar time periods.

- As it is the ex post costs that are relevant for evaluating policy, it can be seen that the benefits from the policies are likely to outweigh the costs of policy, probably by a significant amount.

For the **electricity sector**, when compared to the 'without policies' scenario, the benefits of all air quality improvements achieved and projected are as follows[8]:

- Annual benefits by the end of the evaluation period (by 2001) are estimated at £1,316 million (central low estimate) to £5,589 million (central high estimate).
    - By 2010, the annual benefits (undiscounted) are projected to rise to £2,122 million (central low) to £9,930 million (central high).
- Total benefits in the evaluation period (1990 – 2001) are estimated at £10,809 million (central low) to £50,608 million (central high).
    - When the benefits in the entire relevant period of the study (1990 – 2010) are considered, the total discounted benefits rise to an estimated £25,764 million (central low) to £120,402 million (central high).
- Not all of these benefits can be attributed to air quality policies. Although environmental legislation and international commitments are in place and have affected the out-turns, the environmental targets have been largely achieved because of energy policy (privatisation and liberalisation policy). However, in the absence of these policies, there are international emissions commitments that would have provided a policy back-up for most of the benefits seen. We estimate that 38 to 100% of the ESI benefits above can be directly attributed to air quality policies, depending on the assumptions made.
- The benefits above do not include ecosystem benefits, which we have not been able to quantify and value. They also do not include trans-boundary effects (i.e. benefits in Europe from a reduction in UK emissions) or the benefits that have occurred in the UK from reductions in European emissions associated with the same legislation. These three omissions would be expected to increase the benefits very significantly.
- The additional annual benefits from CO_2 reductions in the ESI[9] have been estimated at £665 million to £2,660 million by the end of the evaluation period (2001), when compared to the 'without policies' scenario. This is projected to rise to a benefit of £1,142 million to £4,568 million by 2010. The total benefits in the evaluation period (1990 – 2001) are estimated at £5,193 million to £20,770 million, rising to £8,800 million to £35,200 million in the period 1990 – 2010. These benefits have occurred alongside the improvements in air quality, though they have not occurred directly as a result of air quality policies.

The benefits can be compared against the costs of the policies. For the ESI, the estimated costs are:

- The total ex ante costs of the UNECE protocols were estimated £5,409 million (low) to £29,705 million (high) for the evaluation period (1990-2001). These are similar to our range of estimated benefits from these policies over the same period (£7,413 million to £34,521 million). Note the benefits exclude the effects on ecosystems and trans-boundary effects.
- The total ex post costs of the policies are more difficult to estimate accurately, but it is clear that they are far lower than indicated by the ex ante analysis. We estimate that they are likely to be below £2000 million for the evaluation period. The benefits are therefore much higher than the ex post costs, i.e. the benefits outweigh costs of the policies, probably by a significant amount. The addition of ecosystem and trans-boundary effects would increase the benefits further.

[8] Note these total benefits are from emissions in the time period 1990 – 2010 only. They do not include benefits from lower emissions in future years (post 2001 for the evaluation or post 2010 for the projected analysis) from a move to sustained new pollution levels. Annual values are the benefit in the individual year (2001) compared to the predicted out-turns 'without' policy for that year.

[9] Estimated using the Government recommended illustrative range for the social cost of carbon of £35/tC to £140/tC. Note this value is the subject of a current review.

- Overall, we find slightly higher benefit to cost ratios for the electricity sector policies than for road transport sector policies in the evaluation period[10].

The economic costs and benefits for both sectors are summarised in the table below. The summary values, and the underlying analysis of individual policies, show two clear trends:

- Firstly, there is a good justification (benefit to cost ratio) for the air quality policies implemented in both sectors, i.e. when comparing estimated actual benefits from policies against the 'ex post' costs. The 'central low' estimate of benefits is generally similar in level to ex post costs, and the 'central high' estimate of benefits is many times greater than these costs.
- Secondly, the 'ex ante' costs estimated in the appraisals are higher than the actual benefits estimated here (the ex ante costs have been significantly higher than the 'central low' estimate of benefits and usually a similar magnitude to the 'central high' estimate of benefits). This is important, because it implies that these policies might not have been justified on the basis of a cost-benefit analysis before the policies were introduced[11].
- These conclusions have important lessons for future policy appraisal (discussed later).

Economic Costs and Air Quality Benefits, relative to expected out-turn without policies.
1) Evaluation period (to 2001) and 2) Projected (by 2010).

	1) Evaluation Period (1990 – 2001) £ Million		
	Ex Ante Cost (low to high)	Ex Post Cost (low to high)	Ex Post Air Quality Benefit (Central low to Central high)
Road Transport	£16,109 to £22,807	~£2000 to ~£4000*	£2,941 to£18,370
ESI – all measures	~£6,000 to ~£30,000	~£2000	£10,809 to £50,609
	2) Total Study Period (1990 – 2010) £ Million		
	Ex Ante Cost (low to high)	Ex Post/Projected Cost (low to high)	Ex Post/Projected Air Qual. Benefit – (Central low to Central high)
Road Transport	£46,917 to £67,351	Not known yet	£8,721 to £51,510
ESI – all measures	Not estimated	Not known yet	£25,764 to £120,402

We stress that the ex post costs for the road transport sector are indicative only. We highlight that a further detailed ex post evaluation is needed to confirm this value.

Note only UK benefits are included – the benefits from the reduction in trans-boundary pollution from the UK to Europe are not included. These also do not include benefits to the UK from emissions reductions in other European countries, because of the implementation of the same policies. Environmental benefits do not include all benefits, with a number of areas excluded including impacts on natural and semi-natural ecosystems. The analysis does not include the effects of NO_X emissions on ozone formation. Note only air quality benefits are shown – any possible benefits from CO_2 reductions that have occurred alongside these air quality benefits are not included. Note benefits are from emissions in the period 1990 – 2010 only. They do not include benefits from lower emissions in future years (post 2001 for the evaluation or post 2010 for projected analysis) from a move to sustained new pollution levels.

All of the costs and benefits for the road transport sector can be attributed to air quality policy. The costs and benefits shown for electricity represents the total seen in the sector over the period, however, not all of these can be directly attributed to air quality policy.

[10] Despite the undoubted success of the actions in improving air quality in the ESI, the nature of these measures (i.e. liberalisation) means that they cannot be repeated within the UK. There is also the potential for a reversal of the trends, should e.g. gas supplies become more expensive. This did happen with increases in coal use in 2000 and 2001.
[11] In practice, earlier appraisals did not include full benefits analysis, and so this issue did not arise

Comparison of Ex Ante and Ex Post Costs

The study was asked to consider '*How the costs made before the legislation was implemented (ex-ante) compare with actual costs after implementation (ex-post)?'*

It has often been suggested that in 'ex ante' studies, costs are systematically overestimated and the benefits underestimated. The analysis here, summarised in the table above, provides evidence to back this up for the two sectors considered. The analysis of individual ex ante and ex post costs has shown that in most cases, ex ante costs were over-estimates. In many cases, these over-estimates were very significant. Note this also leads us to the conclusion that *legislation itself acts as a spur to research and innovation.* However, we also have found some cases where ex ante costs were underestimated, including one example for a major piece of air quality legislation.

Comparison of Individual Policies

The study has considered 'w*hich policies have been successful and which have not?* To do this we have considered the costs and benefits of the individual policies in each of the two sectors:

- For the **road transport** sector, the most successful policies, in terms of the ratio of benefits to costs, have been the earlier policies, such as the introduction of unleaded petrol, 1996 low sulphur levels, and Euro I emission standards. Of these, the introduction of the Euro I standard has had the greatest total benefits of any of the transport policies assessed. As would be expected, later fuel quality and vehicle emissions policies have lower benefit to cost ratios, reflecting the fact that earlier policies have already led to significant emissions reductions. The fuel quality policies have been very successful in the evaluation period, through the use of market-based instruments (duty differentials), which have encouraged the rapid uptake of cleaner fuels. The later command and control legislation introduced from Europe (i.e. vehicle emission 'Euro' standards) have not had full effect within the evaluation period, because these policies require replacement of the vehicle fleet. Nonetheless, the later Euro standards lead to very large absolute economic benefits, and are essential in ensuring progress towards the air quality objectives.
- For the **electricity** sector, the analysis is more complex, due to the combination of environmental and energy policies. The benefits from achieving the emission reductions associated with the UNECE Sulphur Protocols are extremely large, and have extremely high benefits when compared to the ex post out-turn. As a policy commitment, they have therefore been extremely successful (probably more so than any other single policy assessed here). However, care must be taken not to over emphasise the importance of the protocols. Whilst they provided a useful policy objective and also a legal backstop to ensure a minimum level of emissions reduction, they would have occurred in the absence of the policy. The targets were actually achieved from the 'dash for gas' and the introduction of Integrated Pollution Control (IPC) and so care must also be taken not to double count the benefits of the UNECE target with these policies. The introduction of natural gas has high benefits to costs. While increased gas used has primarily arisen from energy policy, there is also an influence from specific air quality policies. The measures introduced under IPC (FGD, low sulphur coal, low NO_X burners, particulate abatement) were a specific air quality driven policy initiative, and have been shown to have a high ratio of benefits to costs. Finally, the analysis of renewable policy (NFFO) shows much that the estimate of 'ex post' costs lies between the low and high estimate of benefits. This policy was introduced primarily to address market imperfections (environmental externalities) and so is partly driven by air quality policy. We have also assessed the benefit to cost ratio for individual NFFO rounds: this indicates that for early NFFO rounds the benefits were less than the costs, but for later rounds, this was reversed and the benefits exceeded costs.

Lessons for Future Air Quality Policy

The study was asked to consider 'w*hat are the lessons for future air quality policy?'* The most important points are summarised below:

- For the **transport** sector, it is possible that the UK may now be at the stage where targeted local action is more cost-effective than national level policies, at least for the pollutant **NO_2**. This is because the remaining exceedances of the NO_2 objective are mostly in the centres of large urban areas. The evaluation has undertaken a separate piece of work to investigate this. The initial results show that local measures which target air pollution may be a cost-effective approach compared to future national measures (such measures also have good benefit to cost ratios). For broader urban transport measures, primarily targeted at improving congestion or traffic flow, the situation is more complex. When considered only in terms of air quality, these broader local measures have a low ratio of benefits to costs. However, when other factors are taken into account (e.g. travel time) the ratio of benefits to costs improves dramatically. This raises the issue of whether future policy should concentrate on local measures targeted primarily towards improving local air quality, or towards local measures that give the greatest overall benefits across the urban environment (i.e. towards wider urban sustainability objectives including congestion, accidents, air quality, noise, quality of environment, etc). This warrants further investigation.

- The study has revealed some interesting points in relation to the NO_2 objective and future policies for NO_2/NO_X. These are summarised in the following points:
    - The NO_2 objective is currently being met in the great majority of the United Kingdom and cost-benefit assessment alone does not support further action beyond the existing objective for NO_2. This is because NO_2 is probably a threshold pollutant (at least for short-term exposure)[12], unlike, for example, PM_{10}. Once the standard has been achieved, there are no additional health benefits from reducing concentrations further. Indeed there is little justification for the current NO_2 objective when considered in terms of cost-benefit analysis alone. In other words it is not an economically optimal target, set on the basis of cost-benefit analysis, but one that seeks to ensure environmental protection and environmental justice. There are however additional benefits from reducing NO_X emissions, the precursor to NO_2 (see below).
    - The NO_2 objective, and further action to reduce NO_X, may be justified in cost-benefit terms when these additional secondary pollutants (nitrates and ozone) and additional impact categories (ecosystems) are included[13]. However, as these are regional pollutants, locally based objective levels are not as relevant. Therefore, future policy might achieve greater overall health and environmental benefits by considering different policy approaches, e.g. by trying to reduce overall population weighted exposure to these secondary pollutants rather than focusing on hot-spots. This is highlighted as a research priority.

- For **SO_2** as a gas, further progress against the air quality targets will lead to low benefits, as there is already projected compliance with the objectives (due to the policies evaluated here). However, there are likely to be health and non-health benefits below the objectives, not least because of the role of SO_2 in secondary particulates (secondary PM_{10}).

- There are also some potentially important messages for the pollutant **PM_{10}**. It is widely accepted that there is no safe population threshold for PM_{10} and national level policies would still be very beneficial. Further PM_{10} reductions will have continued health benefits.

- The location of primary PM_{10} emissions is important and needs to be addressed in future policy. The greatest health benefits, per tonne of PM_{10} abated, will occur in London and larger urban areas. This is because these areas have higher population densities (and so emission reductions lead to a much greater reduction in population weighted exposure). Emissions reductions in these areas are therefore likely to be much more cost-effective, as they have order of magnitude greater

[12] There is some evidence of effects for long-term exposure, e.g. from the US, though there are problems distinguishing the effect of NO2 from particles. Recent WHO guidance is therefore that the current 40 microgram/m3 guideline value should be maintained or lowered.

[13] We highlight that an uncertainty analysis undertaken in the current study has established that there is a lower confidence attached to the health effects of nitrates (secondary PM_{10}), which might further weaken the case for future action for this pollutant.

benefits than say emission reductions in rural areas. This may also mean that future policy will be more cost-effective (in improving health) if it is targeted towards specific sources. To illustrate, for road transport PM_{10}, we know that heavy goods vehicles undertake most of their vehicle kilometres on motorways. A more cost-effective approach to targeting PM_{10} emissions from road transport in urban areas might therefore be to target the diesel light goods vehicle fleet at a national level, reflecting their higher urban activity levels. Further investigation of these issues is highlighted as a research priority from the study.

- The analysis has shown that reductions in primary PM_{10} emissions from the **electricity** sector have much lower health benefits (per tonne of pollution emitted) than the road transport sector. The difference is almost a factor of 50. Again this is due to the population exposed from different emission sources. We therefore conclude that further action to reduce primary PM_{10} is likely to be much more cost-effective (in reducing health impacts) in the road transport sector. However, it is also necessary to consider the role of secondary particulates and PM_{10}. The study has also shown that the reductions in SO_2 from the ESI have led to extremely large reductions in secondary PM_{10} concentrations, even though this was not the primary policy aim (the primary aim being SO_2 reductions). Future policies in the ESI might achieve greater health improvement by reducing SO_2 emissions (in order to reduce secondary PM_{10}) rather than targeting primary PM_{10}. The analysis of the relative contribution of the two sectors in reducing remaining PM_{10} (and their cost-effectiveness) is highlighted as a major research priority.
- The ESI has much lower benefits in reducing population-weighted exposure to NO_2 than the transport sector. Given most exceedences are at road-side in future years, further reducing NO_X emission from the ESI is not a particularly targeted way of progressing towards the NO_2 objective. However, the health benefits of reducing NO_X (through reductions in secondary particulates (nitrates)) have been found to be very similar per tonne of pollutant emitted in the electricity generation and the road transport sectors. As the impacts from NO_X are now dominated by secondary species (the formation of ozone and nitrates), it may be that further action to reduce NO_X from the ESI is as effective in terms of health benefits as from the road transport sector.
- The convergence between energy and environmental policy in the ESI highlights that there can be significant benefits from linking environmental changes to other changes going on within industry. For example, the structural changes that occurred due to gas liberalisation provided the opportunity to set stricter controls on SO_2 emissions than might otherwise be the case. There may be other cases where a policy change in other areas could be used to drive environmental change, and this warrants further investigation.
- Since 1990, the average air pollution impacts from the UK electricity generating mix have fallen very dramatically. This trend will continue through to 2010. There is also an important, but smaller reduction in CO_2 emissions over the same period. For the transport sector, average air pollution impacts have also reduced dramatically since 1990 and are predicted to further decrease through to 2010. However, this has not been accompanied by a reduction in CO_2 emissions. This leads to the final issue raised for future air quality policy. At the start of the 1990s, the environmental costs of electricity generation and transport were dominated by air pollution. By 2010, although total air pollution costs will still be high, the air pollution costs per kWh or per vehicle km will be significantly reduced. However, because the emissions of carbon (and associated environmental costs) have not changed as much over this period, the relative environmental costs of air pollution and carbon are now much closer. While important air quality issues remain, it is likely that carbon emissions will become a much greater environmental driver in policy. A greater focus on combining air pollution and greenhouse gas mitigation policy will therefore be needed for future policy.

A number of other conclusions have been made, based on sensitivity analysis, which have relevance for future policy.

- We have greatest confidence in the health impacts of primary PM_{10} emissions. There is a lower confidence in the impacts of sulphates, and still less in the effects of nitrates. Policies targeted at reducing primary PM_{10} (especially in the road transport sector, which has a greater proportion of $PM_{2.5}$) are therefore identified as a priority. This may have implications for targeting future policy

- Related to this, any change in the health impacts attributed to different parts of the PM_{10} mixture will have a major influence on the pattern of benefits from existing policies (and also future policy). A sensitivity analysis undertaken here has shown that if greater emphasis is given to primary $PM_{2.5}$ (as per recent WHO communications), this would increase the benefits of road transport sector policies very dramatically (even though it would reduce the benefits of reducing nitrates).
- There are potentially a large number of additional health benefits from air pollution reductions, i.e. acute morbidity effects. Using health impact assessment approaches from other studies (including the US) dramatically increases the numbers of health impacts, though the increase in the economic benefits from these effects is modest, relative to the main effects already captured in UK appraisal.
- Whilst very large emissions reductions have occurred for CO and NO_2 from road transport policies, and targeting these pollutants was the primary reason for transport sector air quality policy, the economic benefits of these reductions are extremely low (though note NO_X still has potential benefits through the reduction of the secondary pollutants).

Future Appraisal and Research Recommendations

Finally, the study was asked to evaluate '*what lessons are there for future appraisal? What information is needed to help inform the development of future air policy?*'

We stress that the quality of appraisals has significantly improved over the period, i.e. from 1990 to 2002. Modern studies have much more rigorous economic analysis and better benefits analysis. However, there are a number of suggestions for improving future appraisals. These are set out below.

1) Cost Estimates (Ex Ante). The finding that ex ante costs have typically been over-estimated, often very significantly, is an important conclusion for future policy appraisal. Based on this, a number of recommendations are made for future ex ante cost analysis (appraisal), with respect to the sort of study undertaken here. These are.

- To improve access to literature, particularly for earlier studies;
- To improve the access to disaggregated cost analysis in all studies, to allow consideration of the data at a later stage;
- To improve the reporting of information (discount rates, year, baselines);
- To develop frameworks for reporting and dealing with uncertainty;
- To ensure critical independent review.

We also stress that future ex ante cost studies and appraisals should consider the potential uncertainty inherent in the cost numbers. This could be undertaken through formal uncertainty analysis (e.g. using statistical packages) or through wider expert consultation. This is particularly important, because in cost-benefit analysis, the 'typical' assumption has been that the cost estimates are far more accurate than the benefits analysis. The data in this study shows that this conclusion is rarely valid.

The study has also looked at the wider economic costs in appraisal, as should be covered by a full regulatory impact assessment. The lack of ex post studies makes it difficult to assess the wider economic costs of the policies, though it is anticipated that these effects are low. In relation to this area, we argue that there should be adoption of consistent estimation approaches for future assessment of these effects prior to, and following, the implementation of a policy in order for robust conclusions to be drawn.

2) Quantification of Benefits – Approach Adopted. In the UK, a 'conservative' approach has historically been used in the appraisal of benefits. The benefits quantified and valued using this approach, equivalent to the ‘central low’ estimate of benefits presented in this study, have generally turned out to be much lower than the ‘ex ante’ costs of the policies evaluated here.

The ‘conservative’ approach is consistent with the guidance given by COMEAP. This is not a criticism of COMEAP, which has aimed to estimate effects that ‘could be applied in the UK with reasonable confidence’. Indeed, we stress that this ‘conservative’ approach increases the confidence in the estimates. However, it systematically under-estimates benefits, because it does not seek to quantify the total impacts of air pollution.

It is interesting to note that a more comprehensive approach of appraisal has been adopted for European policy appraisal. This has tried to cover more effects, albeit acknowledging that this increases the uncertainty of the estimates[14]. The benefits quantified and valued using this approach, equivalent to the ‘central high’ estimate of benefits presented in this study, have turned out to be similar or greater to the ‘ex ante’ costs of the policies evaluated here. Therefore the choice of appraisal methodology adopted may have a strong influence in determining whether future policies pass a cost-benefit analysis.

Using a ‘conservative’ approach introduces bias to appraisal (it under-estimates benefits). This is compounded because the analysis above has shown that costs are often over-estimated. Moving to an approach that assesses the full ‘social cost of air pollution’ may therefore appear a more pragmatic one for policy appraisal, though it also carries some risk. For example, where policies are made on the basis of weak evidence that actually (later) turns out to be false[15]. On the basis of the analysis here, the following suggestions are made for future appraisal.

- Our main recommendation is that it is imperative that much more attention is focused on sensitivity and uncertainty analysis for estimating benefits in appraisal. We also believe that the greatest strength for future policy appraisal is to cover both approaches outlined above, i.e. to start with the relatively ‘conservative’ approach recommended by COMEAP, but to extend this to try and assess the total impacts of air pollution. Within this process, the uncertainties that are present in the analysis should be made clear, through confidence or uncertainty categories that are relatively easy to understand.

- It would also be useful for COMEAP to consider the plausibility of other impacts such as secondary vs. primary particles, other PM_{10} functions (including chronic morbidity, childhood mortality, etc) and other ozone effects (that have not even been quantified here), in order to ensure that the benefits analysis can be kept up to date. The first of these is particular important, as sensitivity analysis undertaken in the report has indicated that the assumptions in relation to the health impacts of different elements of the PM_{10} mixture (i.e. primary, sulphates, nitrates, etc) have a major effect on the benefits of future policies, by sector and pollutant.

3) Quantification of Benefits – Which Benefits. The next issue for future appraisal is in relation to the types of benefits included. There are four issues identified.

Firstly, future air quality policies should take account of secondary pollutants, such as ozone and secondary particulates. The modelling and analysis of these pollutants is complex and time consuming, and this will have potential implications for the resources needed for future appraisal.

- One way around this would be to provide some simplified analysis (e.g. costs per tonne) for secondary pollutants, based on comprehensive modelling, to allow a wider body of policy makers

[14] European cost-benefit analysis (e.g. in the Clean Air for Europe Programme) aims to generate an unbiased set of estimates of the effects of air pollution on health, along with guidance on the reliability of those estimates. To do this they have recommended an approach that is designed to neither systematically *over*-estimate or *under*-estimate the health effects. Such an approach requires greater focus on sensitivity and uncertainty analysis.

[15] For example, there are fewer risks if a bundle of pollutants are reduced, rather than focusing on one pollutant. However, an approach that targets all pollutants is less efficient.

to be able to consider these effects alongside the traditional (current) analysis undertaken. We highlight that this is one of the major research priorities from the study, and suggest Defra investigate a similar policy tool to the EC's BeTa model, which has cost per tonne estimates for air pollution appraisal.

Secondly, it is important for UK policy appraisal to consider whether trans-boundary pollution and benefits should be included in UK specific studies. To date, the potential benefits to continental Europe from emission reductions in the UK have not been quantified or valued in UK appraisal, even though these benefits have been one of the key drivers in the reduction of certain pollutants (e.g. SO_2 and VOCs). As well as covering the 'export' of pollution, appraisal also needs to take account of the benefits to the UK, from emissions reductions in Europe – as European policies will lead to additional benefits to the UK that are not currently captured in many appraisals (i.e. the reduction in 'imports').

- We believe future appraisal should cover these 'imports' and 'exports'. Again, modelling these effects would be very time consuming, and we recommend the development of a policy tool, linked to the research priority identified above.

Thirdly, there are some issues concerning the time-scale of costs and benefits in appraisal. Most (but not all) of the costs estimated involve technical equipment, the costs of which are usually assessed over a defined life-time (e.g. 15 years). In the analysis above, the benefits have been assessed over the same life-time, consistent with previous practice in appraisal. However, in practice, the benefits will continue for future years beyond this time, after the capital costs of the plant have been recovered. This may lead to a situation where appraisal underestimates the full benefits from policies.

- We believe some consideration should be made of the appropriate time-scales for consideration of costs and benefits.

Fourthly, future air quality policies need to be strongly linked with greenhouse gas emissions reductions. This is important because the air pollution costs of the transport sector and ESI have reduced enormously since 1990 - and are predicted to continue falling to 2010. With respect to the full social costs of road transport or electricity production, the social cost of carbon will become as important (if not more so) than the social costs of air pollution. This is in strong contrast to the position in the early 1990s.

- Policies therefore need to adopt a more holistic approach to environmental policy making, with closer links needed between air quality and climate change policy.

Finally, the study has identified a number of other areas that warrant future research. The most important of these are summarised below:

- It is stressed that the study here has only considered two sectors, albeit the most important ones from the perspective of air quality improvements. We stress that further work is needed to undertake an evaluation of AQS policies in the other sectors, particularly the industrial and domestic sectors. The evaluation of these sectors is highlighted as one of the main research priorities from the study.
- Future air quality policy should consider the cost-effectiveness of pollution reductions from different sources, given that the benefits of emissions vary according to the location of emissions (very significantly). These could include analysis of activity data within sectors as well as between sectors. The consideration of primary and secondary pollutants, and the relative health benefits from reducing both, should also be considered.
- It would be useful to investigate some of the impacts not quantified here, at least to see if potentially they might be important omissions to the benefits quantified. Particularly important are additional health impacts.
- A policy tool should be investigated, as follow-on to the work presented here, to enable the consideration of secondary pollutants and trans-boundary pollution in appraisal. This would

simplify a number of the more complex and time-consuming elements of appraisal, and allow consistency in future estimates across Government.