4 Conclusions

4.1 Emission Reductions and Air Quality Benefits of the Policies

4.1.1. The policies introduced in both the road transport sector and ESI have been extremely successful in reducing emissions of the main regulated pollutants, relative to a 'no abatement' scenario[71] and also relative to 1990 emissions. The emissions of the key regulated pollutants under the 'no abatement' and with all policies, are shown in the figure below for the road transport sector (left) and the ESI (right). The figures for each pollutant are plotted on the same scale to show the absolute reductions achieved in the two sectors.

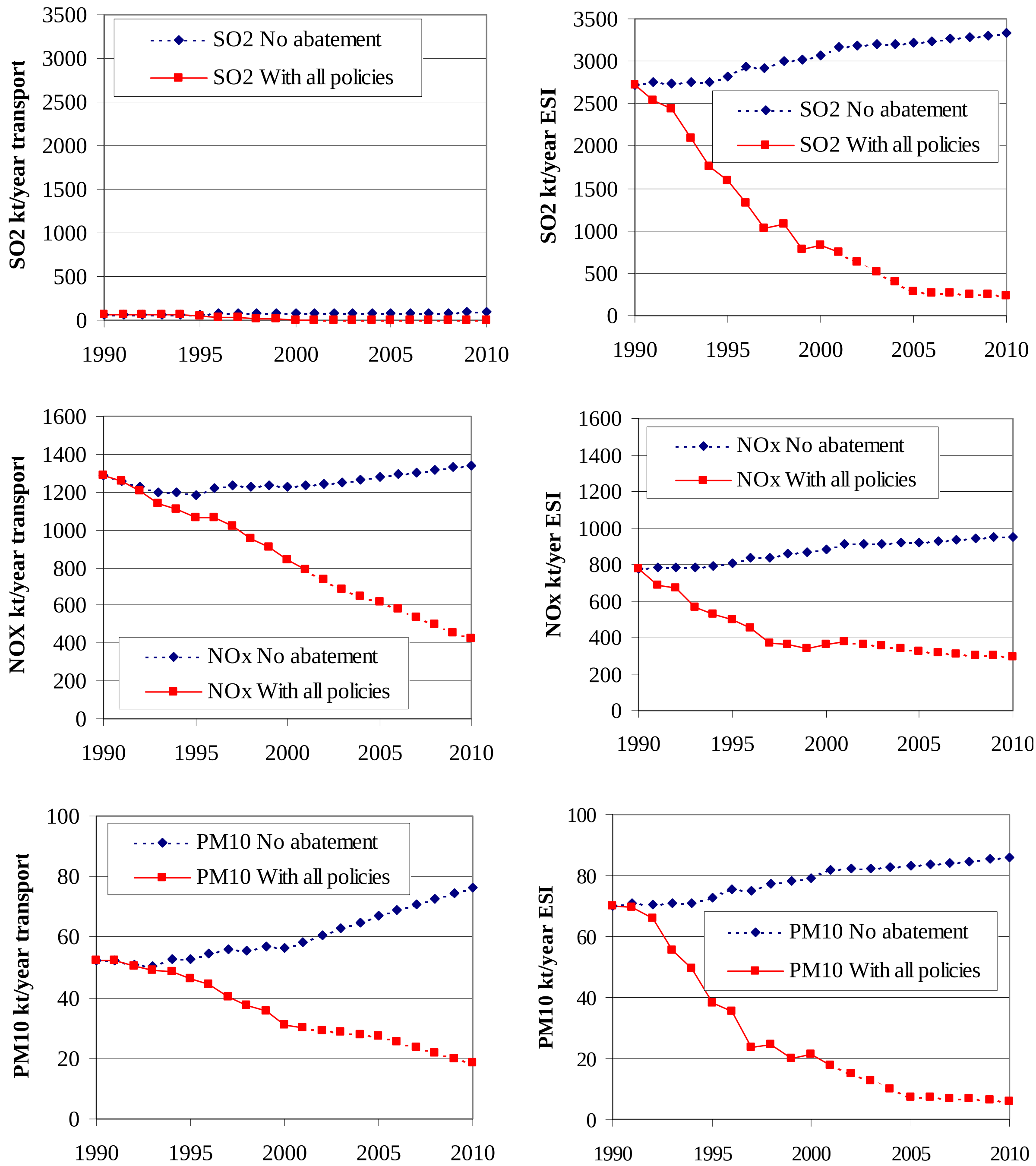
4.1.2. The figure shows that:

- **For sulphur dioxide (SO_2)**, the policies introduced have already led to a 96% reduction in emissions from the road transport sector in the evaluation period (by 2001), and a 77% reduction in the electricity generation sector, when compared to the equivalent 'no abatement' scenarios. Projecting through to 2010[72], the policies are expected to lead to a 96% reduction of emissions from the road transport sector and a 93% reduction of emissions from the ESI sector, compared to the 'no abatement' scenarios. However, the ESI has much greater emissions of SO_2, and is responsible for a very much larger absolute reduction (in tonnes) of UK SO_2 emissions to date, and estimated future reductions.
- **For oxides of nitrogen (NO_X)**, the policies introduced have already led in the evaluation period (by 2001) to a 36% reduction in emissions from the road transport sector, and a 58% reduction in the electricity generation sector, when compared to the equivalent 'no abatement' scenarios. Projecting through to 2010, the policies are expected to lead to a 69% reduction of emissions from the road transport sector and a 69% reduction of emissions from the ESI sector, when compared to the 'no abatement' scenarios. However, larger absolute reductions (in tonnes) have been achieved to date the road transport sector (and will occur in the future) because of the higher baseline emissions.
- **For particulate matter (PM_{10})**, the policies introduced have already led in the evaluation period (by 2001) to a 48% reduction in emissions from the road transport sector, and a 78% reduction in the electricity generation sector, when compared to the equivalent 'no abatement' scenarios. Projecting through to 2010, the policies are expected to lead to a 76% reduction of emissions from the road transport sector and a 93% reduction of emissions from the ESI sector, when compared to the 'no abatement' scenarios.
- It is stressed that all of the emission reductions from road transport policies can be attributed directly to air quality policies. However, not all of the emission reductions in the ESI can be attributed to air quality policy. We estimate that in the evaluation period, between 38 to 100 % of these SO_2 emissions reductions, 34 to 100% of these NO_X emissions reductions, and 46 to 100% of these PM_{10} emissions reductions can be attributed to air pollution policy

[71] 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 the effects would be more important for the ESI, and thus the results for this sector have higher uncertainty.

[72] Note for the 2002 – 2010 period, we have extended the 'without' policies scenario from the 1990 – 2001 path, i.e. we have not re-assessed the baseline conditions in 2001. We stress that this analysis was consistent with the best available information at the time, based on the 2001 NAEI projections. The NAEI has been subsequently for both road transport and the ESI.

Road Transport Sector **ESI Sector**



Effect of Policies on UK Emissions of Regulated Pollutants by Sector.
Solid lines represent actual data (to 2001). Dotted lines represent projections.

Note for the road transport sector, the ‘no abatement’ (no policies) scenario has assumed vehicles would otherwise conform (today and future) with pre-Euro 1990 standard vehicle emission standards and fuel types. However, emissions are increased to take account of the actual traffic growth over the period. For the ESI, we have also assumed that the fuel mix in the ‘no abatement’ (no policies) scenario would otherwise conform to 1990 technology and fuels, and emissions are adjusted upwards in line with actual electricity demand growth. However, we stress that different policies in place in the ESI would have led to changes in the price of electricity. It has not possible within this study to model the effects of different policies on electricity prices and we highlight this an uncertainty in the analysis.

All of the emissions reductions for the road transport sector can be 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.

4.1.3. The policies have also led to a reduction in emissions of other pollutants.

- The policies introduced in the road transport sector have already led to a 99% reduction in lead emissions in the evaluation period (by 2001), relative to the ‘no abatement’ scenario.
- The policies introduced in the road transport sector have already led in the evaluation period (by 2001) to a 60% reduction in VOC emissions, a 42% reduction in carbon monoxide (CO) emissions, a 84% reduction in benzene emissions, a 54% reduction in 1,3-butadiene emissions, a 56% reduction in benzo[a]pyrene, relative to the ‘no abatement’ scenario. Projecting forward, by 2010, the policies are expected to lead to a 81% reduction in VOC emissions, a 78% reduction in carbon monoxide (CO) emissions, a 93% reduction in benzene emissions, a 84% reduction in 1,3-butadiene emissions, a 85% reduction in benzo[a]pyrene, relative to the ‘no abatement’ scenario.
- The policies introduced in the electricity generation sector (by 2001) have already led to a 30% reduction in CO_2 emissions, when compared to the equivalent ‘no abatement’ scenario. This is projected to increase to a 43% reduction by 2010. Significantly, there has also been a major reduction in carbon dioxide (CO_2) emissions in absolute terms, relative to the 1990 baseline (the relevant date for the Kyoto protocol and UK domestic targets). In contrast, there has been almost no reduction in CO_2 emissions from the road transport sector relative to the no abatement scenario, and importantly, emissions have strongly increased from the 1990 baseline (in absolute levels) due to increasing transport activity. Note the CO_2 reductions have occurred alongside the improvements in air quality, though they have not occurred directly as a result of air quality policies.

4.1.4. The study has also assessed the emissions reductions of individual policies in the two sectors. For the **road transport** sector:

- The greatest emission reductions (relative to a ‘no abatement’ scenario) have been achieved by fuel-based standards, which have achieved very large reductions in lead, SO_2 and benzene emissions in the evaluation period. Very high emissions reductions were achieved by 2001 (a 99% reduction in lead emissions, a 93% reduction in SO_2 and a 84% reduction in benzene in 2001, relative to the no abatement scenario). The high improvement seen obviously reflect the removal of lead and sulphur that were present in the fuel. These fuel-based policies have been introduced (largely) in the UK through duty differentials. The use of these market-based instruments has been extremely successful in the rapid uptake of cleaner fuels.
- The command and control legislation introduced from Europe (vehicle emission standards – the ‘Euro’ standards) has also been extremely effective in reducing emissions of all regulated air pollutants. This involves a different set of pollutants to the fuel quality standards above. The reductions achieved in the evaluation period (by 2001) are more modest (as a %) than for the fuel quality standards above, due to the time taken for replacement of the vehicle fleet. Nonetheless, significant emissions reductions have occurred over the evaluation period (generally a 40-50% reduction in emissions, relative to the no abatement scenario). Significant further improvements are projected over the period to 2010 (increasing the emissions reductions to 70 to 85%, relative to the no abatement scenario) as tougher Euro standards enter into force for new vehicles, and as the older vehicle fleet is retired. Particularly significant is that major reductions in NO_X and PM_{10} do occur during this later period.
- The overall success of different Euro standards (as individual emission reduction policies) depends on the importance given to different pollutants. When all eight regulated pollutants are considered, it is the Euro I standard (for petrol cars) that seems to dominate the reductions. However, when the focus is switched to the two pollutants of most

concern for local air quality management, NO_2 and PM_{10}, the reductions arise more evenly from all Euro standards across all vehicles.

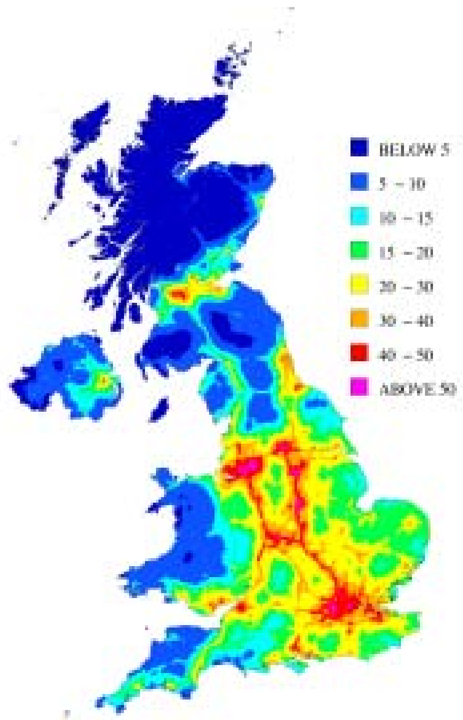
4.1.5. For the **electricity generation** sector, the analysis of individual policies is more difficult. The analysis has looked at the measures that have led to emission reductions, and then allocated these measures to policies (or a combination of policies):

- For SO_2, the UNECE sulphur protocols set policy targets for emission reductions and these have led to very large emission reductions in the evaluation period (and this will continue through to the target date of 2010). The main measure that has led to the emissions reductions has been the switch to natural gas, followed by the introduction of FGD, and in recent years, the growing use of low sulphur coal. The latter two measures are a direct result of national Integrated Pollution Control policy. Note the emission reductions that have been achieved for SO_2 emission reductions go beyond that required by the protocol.
- For NO_X, the largest reductions have arisen from the introduction of natural gas use, though the introduction of low NO_X burners (coal) is also important. The latter measure has been introduced because of IPC. There are also emission reductions from the increase in renewables.
- For PM_{10}, the largest reductions have occurred from gas use and (to a lesser extent) particulate control on coal plant and the introduction of FGD (the latter two from IPC).
- The policies responsible for increased gas use are mostly attributed to market liberalisation but were also influenced by the economic attractiveness of gas plant compared to coal and oil, which were less economically attractive because of European and national environmental policy.

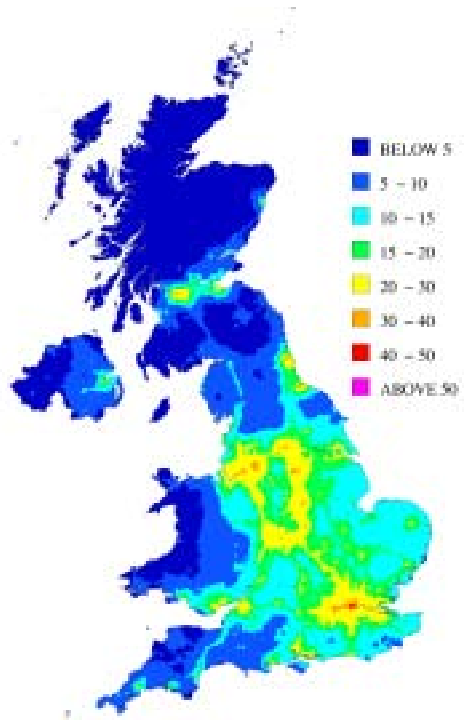
4.2 Progress towards the Air Quality Legislation

4.2.1. The legislation has also been extremely successful in the progress towards the UK and EU air quality targets (objectives/limit values). However, the two sectors have affected different pollutants. The key benefit of the road transport policies has been the reduction of NO_2 concentrations, and so progress towards the NO_2 objectives. The key benefit of the ESI policies has been the reductions of SO_2 concentrations, and progress towards the SO_2 objectives. This can be seen in the figures below. The maps show the concentrations at background across the UK, with the ‘no abatement’ scenario on the left and with ‘all policies in place’ on the right.

4.2.2. Both sectors have had benefits in reducing PM_{10} concentrations. The policies in the road transport sector have been extremely successful in 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.

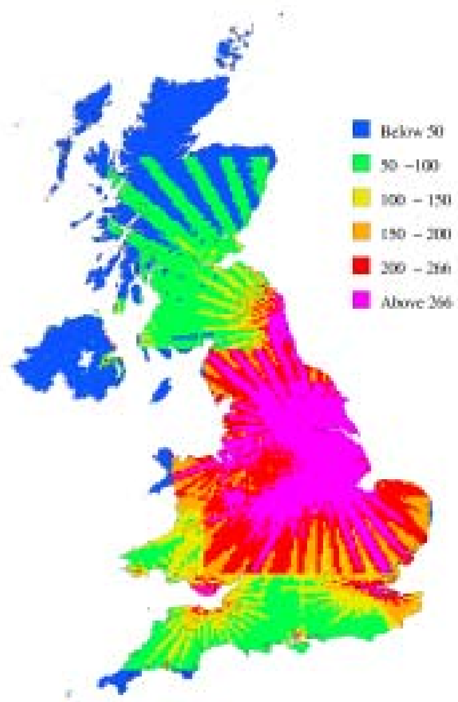


Annual Mean Background NO_2 'No Road Transport Abatement (2010),

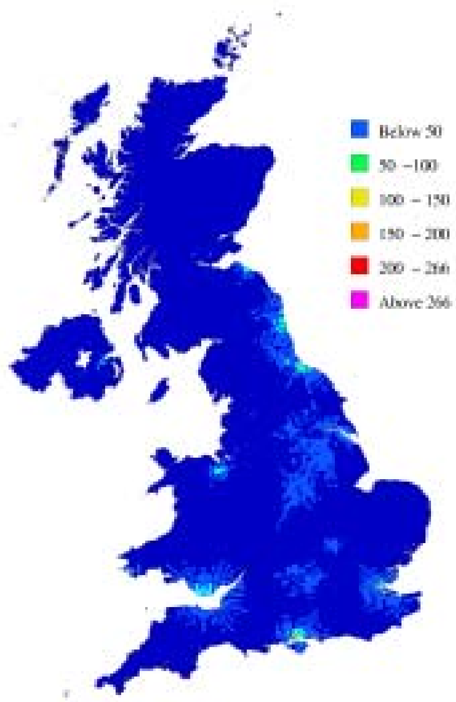


Annual Mean Background NO_2 'All Road Transport Policies' (2010), μgm^{-3}

Note for other sectors (e.g. electricity, domestic, industry), the emissions and their contribution to air quality are based on actual and predicted data with all policies in place – therefore the maps show the incremental difference for air quality in the UK from policies in the road transport sector alone.



15 Minute Mean SO_2 'No Abatement in the ESI' (2005), μgm^{-3}



15 Minute Mean SO_2 'All ESI Policies Abatement' (2005), μgm^{-3}

Note for other sectors (e.g. transport, domestic, industry), the emissions and their contribution to air quality are based on actual and predicted data with all policies in place – therefore the maps show the incremental difference for air quality in the UK from policies in the electricity generation sector alone.

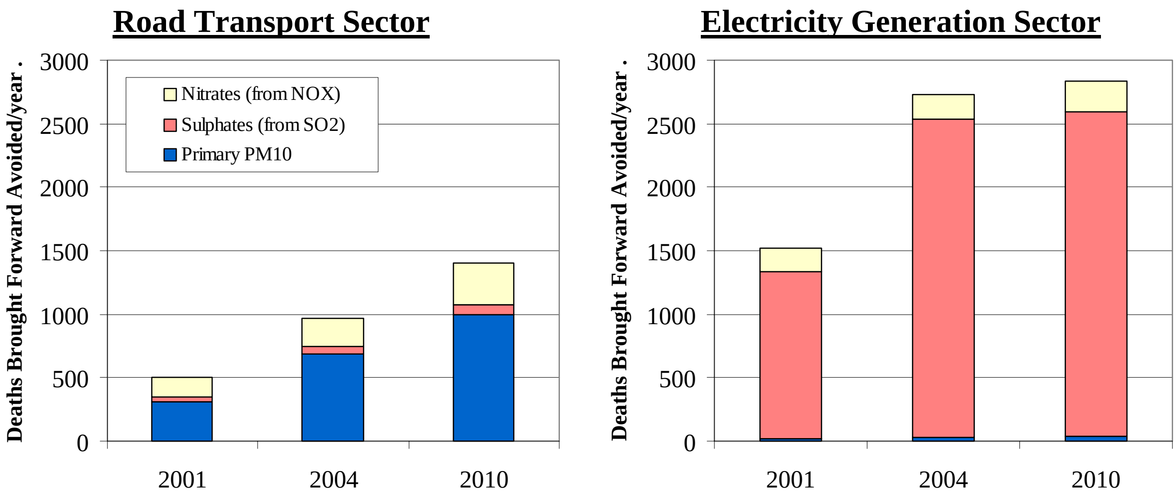
4.3.3. The analysis has also raised interesting issues for future air policy objectives.

- For **NO_2**, it indicates that the benefits of future national road transport policies, in terms of reducing background exceedences, will be low, as most background areas will already have achieved the objective with current policies. Any further improvements in reducing NO_2 nationally will therefore have most effect in reducing exceedences at the roadside, where human exposure is less of an issue. As an objective exists for NO_2, and assuming it is correctly set at the threshold level, then the health benefits of future national policies will also be low. In this case, it is possible that the UK may now be at the stage where targeted action may be more cost-effective than national level policies for road transport, where the remaining areas that exceed the objective are mostly in the centres of large urban areas. For these areas local measures are likely to prove to be more cost-effective, as a more targeted way to tackle urban air quality hot-spots. Further work is needed to test this hypothesis. However, the situation is somewhat less clear if benefits and cost-effectiveness are assessed in terms of health. This is because even when annual average NO_2 is lower than the objective, there may still be benefits to health in further reductions, due to reductions in secondary pollutants formed from NO_X emissions.
- For **SO_2** as a gas, there is already estimated compliance with the objectives with current policies. However, there are likely to be health and non-health benefits in going below the objectives, not least because of the role of SO_2 in secondary particulates (secondary PM_{10}).
- For **PM_{10}**, it indicates that future policies in the both sectors, in terms of progress against the air quality targets will be low. However, it is widely accepted that there is no safe population threshold for PM_{10}, i.e. health impacts occur below the objective. This indicates that national level policies would still be very beneficial with respect to PM_{10}. Note that achieving these PM_{10} reductions could be from further road transport policies, but could also be from reducing SO_2 (and so secondary PM_{10}) from the ESI. 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.

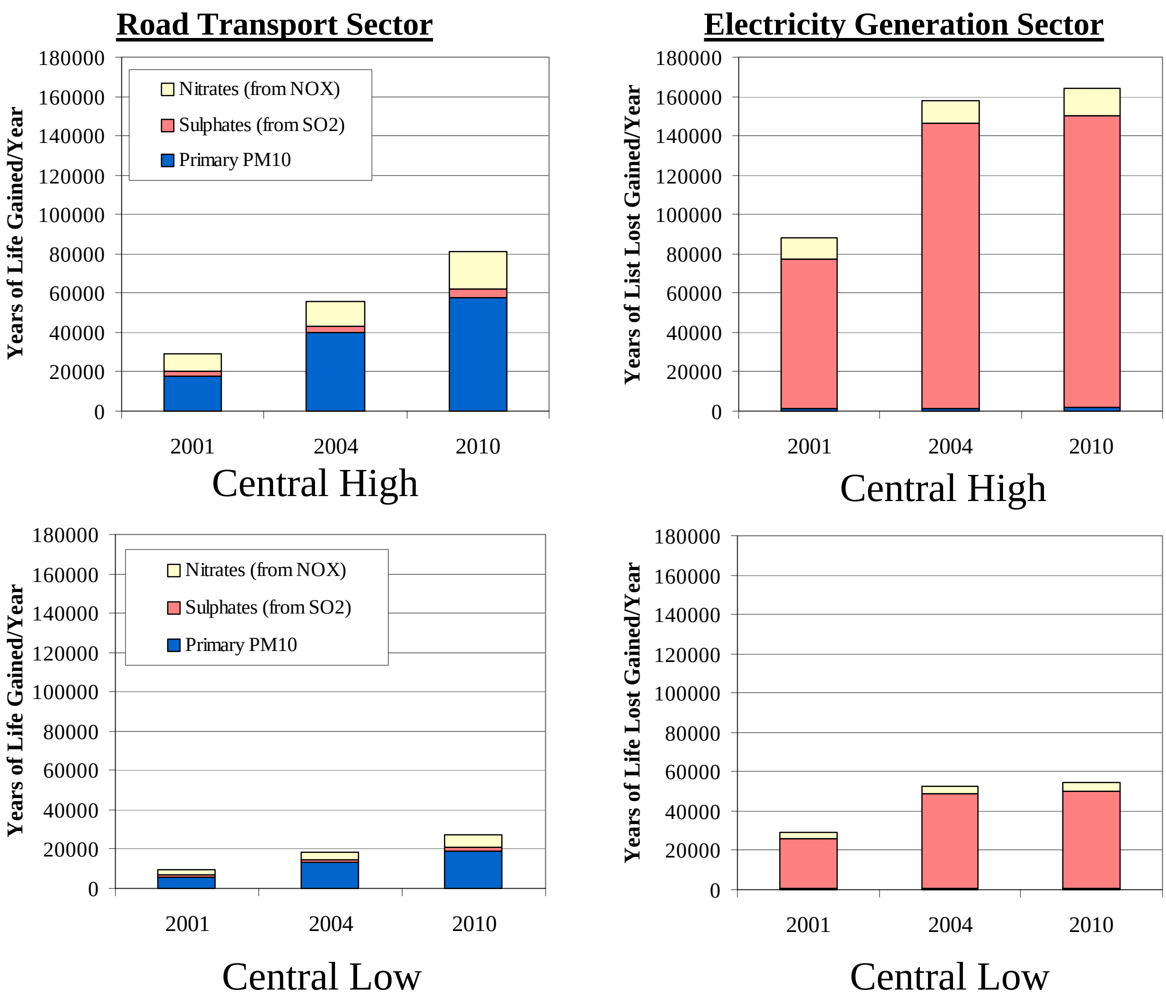
4.3 Health Benefits of the Policies

4.3.1. The air quality improvements from the policies in both sectors have significantly reduced the potential impacts of air pollution in the UK. The study has assessed the health and non-health benefits of the policies in the two sectors, each relative to the ‘no abatement’ scenario.

4.3.2. PM_{10} is the main pollutant of concern in health impacts. The Figure below shows the estimated annual health benefits in the UK from reductions in total PM_{10} in terms of deaths brought forward (top), and life years lost (bottom), from the introduction of the policies in each of the two sectors. This is the benefit from the pollution change in each year compared with the predicted out-turns ‘without’ policy for that year. The values for 2001 are based on the actual data (i.e. they are effectively an ex post analysis). The values for 2005 and 2010 are projected. It is stressed that the benefits include the reduction of primary PM_{10} from vehicle exhausts or power stations, but also the reduction in secondary particulates from NO_X and SO_2.



The benefits, in terms of reduction in DEATHS BROUGHT FORWARD in the UK from primary and secondary PM_{10} concentrations relative to 'no abatement' scenario.



The benefits, in terms of reduction in LIFE YEARS LOST by SECTOR in the UK from primary and secondary PM_{10} concentrations relative to 'no abatement' scenario.

The figures show the differences between the actual out-turn and the 'no abatement' where no road transport policies (left) or ESI policies (right) are introduced (but improvements in other sectors do occur). It shows the benefit from the pollution change in each year compared with predicted out-turns 'without' policy for that year. See main chapters for caveats on quantification and valuation. Note life years are presented (undiscounted) for the year of pollution, but in reality, the change would occur over the lifetime of exposed population.

4.3.3. The analysis shows that road transport policies have already (2001) led to an annual reduction of around 500, in the number of people per year whose life is shortened by pollution in days before death from PM_{10}, and ESI policies around 1500. This is projected to increase to a benefit of 1400 people per year for road transport, and 2800 people per year of the ESI, by 2010[73]. Note all of the benefits in the road transport sector can be attributed to air quality policy. We believe 38 to 100% of the ESI benefits above can be directly attributed to air quality policies. The analysis has also assessed the long-term benefits from road transport policies for PM_{10}, shown as the estimated health effects in the UK in terms of the change in life expectancy, with and without policies.

4.3.4. If both primary and secondary particulates (PM_{10}) are considered, then the benefits from policies in the ESI are almost double that of the benefits in the road transport policies, though not all of the ESI benefits can be attributed to air quality policy. There is, however, a big difference in the pollutants responsible for the benefits between the sectors. For the road transport sector, the benefits primarily arise from reductions in primary PM_{10}. For the ESI, the benefits primarily arise from secondary PM_{10} (sulphates). It is stressed that the inclusion of secondary PM_{10} (sulphates and nitrates) has been included as part of the main analysis[74]. While PM_{10} benefits dominate the health benefits of the policies, there are also additional benefits from reductions of other pollutants. The most important of these benefits arise from the reduction in lead emissions, the reduction in ozone (from ozone pre-cursors, VOCs in particular), and the reduction in SO_2 emissions as a gas (health and non-health effects).

Annual Health benefits, relative to the expected out-turn without policies ('no abatement'), shown as benefits achieved in the evaluation period (to 2001) and projected (by 2010).

Cases avoided each year	**Road Transport ***	**ESI ***
Evaluation Period (in 2001)		
'Deaths brought forward' per year	500	3,725
Respiratory Hospital Admissions/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)
Expected (by 2010)		
'Deaths brought forward' per year	1,400	5,187
Respiratory Hospital Admissions / 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 table shows the benefit from the pollution change in the year 2001 and 2010 compared with the predicted out-turns 'without' policy for that 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, to reflect the range of risk factors for 'chronic mortality' effects.

[73] Note the additional deaths brought forward avoided from SO_2 as a gas and ozone are additive to these values.
[74] COMEAP does quantify secondary particulates identically to primary PM_{10} (because it applies the PM_{10} health functions to all of the PM_{10} fraction), but it has not specifically commented on the application of PM_{10} health functions to sulphates or nitrates. Both of these pollutants are within the PM_{10} size fraction: although it is widely believed that different constituents of PM_{10} are associated with different toxicities to human health, the approach used here would be consistent with a precautionary approach. However, while several studies in the USA and Canada have shown direct relationships between sulphates and various acute and chronic health endpoints, there is no direct evidence linking nitrates to health effects. The study team remain cautious about the causality of nitrates as part of the PM_{10} size fraction and our confidence in the values is lower than for sulphates.

4.3.5. It is interesting to compare these values to the previous COMEAP quantification report (1998) – presented in the box below. The analysis shows that there has been a major reduction in the health impacts of air pollution over recent years, and that the current policies will continue this.

Quantification of Health Impacts from Air Pollution in the UK – an update since the COMEAP analysis.

COMEAP quantified the estimated health impacts of air pollution in the UK in its 1998 quantification report[75]. The report estimated that annually there were 8,100 deaths brought forward and 10,500 respiratory hospital admissions from PM_{10} pollution (based on pollution in 1996) in the UK.

The analysis here estimates that this has fallen to 6,838 deaths brought forward and 6,699 respiratory hospital admissions from PM_{10} pollution in 2001 in the UK. This is the ex post out-turn, based on modelling analysis. The current study has also estimated the future improvement from existing policies. This indicates that by 2010, the health impacts of air pollution in the UK will have fallen to 6,053 deaths brought forward and 5,930 respiratory hospital admissions from PM_{10} in the UK (this is the projected improvement, based on ex ante modelling analysis).

COMEAP did not calculate the years of life lost (chronic mortality), but it is possible to undertake a back-calculation to assess this using the methodology presented earlier (see boxes 2.2 and 2.3 in an earlier chapter). In summary, the analysis of life years saved is based on exposure to PM_{10} experienced for a 1 year pollution increment. It is based on the life-table approach, following up the population exposed to the 1-year pollution change until all have died, assuming no lag effects. Pollution-related changes to death rates are spread over time but in total are equivalent to changing the death rates for one year only by the estimated risk coefficient (i.e. 0.1% or 0.3% per μgm^{-3} $PM_{2.5}$). Values include benefits from both primary PM_{10} and secondary PM_{10}. The numbers presented are undiscounted.

Using this approach, the analysis here indicates that in 1996, the number of life years lost from PM_{10} pollution in 1996 in the UK was 156,044 to 468,133 years of life lost (the range represents our central low to central high estimate – note this is a restricted range). This compares with an annual value of 131,732 to 395,197 years of life lost from PM_{10} pollution in 2001 calculated here as an ex post modelling analysis, and a projected annual estimate of 116,608 to 349,823 years of life lost from PM_{10} pollution in 2010. This shows the large benefits from air quality policies (and the AQS) already in place, and projected to occur from existing legislation to 2010.

Overall it indicates that policy has already led to benefits in terms of thousands of deaths brought forward avoided, and tens of thousands of years of life lost saved.

The benefits for SO_2 are even greater. The COMEAP 1998 quantification report estimated that annually there were 3,500 deaths brought forward, and 3,500 respiratory hospital admissions from SO_2 pollution in 1995 in the UK. The analysis here indicates that this has fallen to 1,273 deaths brought forward and 975 respiratory hospital admissions from SO_2 pollution in 2001 in the UK, and is estimated to fall to 890 deaths brought forward and 681 respiratory hospital admissions by 2010.

4.3.6. Finally, the study has also undertaken an analysis of the **ex post health benefits** of air pollution improvements. This has specifically sought to address the issue of whether better air quality actually leads to better health. We assessed the evidence from studies of health in locations where air pollution has clearly changed. Some of the changes were the intentional result of policies to reduce air pollution – for example, the Dublin coal ban of 1990, or the ban in Hong Kong, also in 1990, on using higher-sulphur oil. These changes led to sustained reductions in air pollution. Other changes in air pollution were side-effects of changes not targeted at reducing air pollution – for example, traffic changes in Atlanta, USA during the Olympic Games of 1996; or the temporary closure of a steel mill in Steubenville, Ohio, during 1986-87. The associated air pollution reductions were therefore temporary also.

[75] Note the COMEAP report also quantified the deaths brought forward and respiratory hospital admissions from ozone. We have not calculated the updated analysis for all ozone concentrations in the UK in this analysis.

4.3.7. The review has shown that in these and similar studies, benefits to health were identifiable very soon after the air pollution reductions – the reductions themselves being quite marked – and were sustained while the pollution reductions were sustained. There are some difficulties methodologically in some studies in attributing unambiguously the changes in health to the pollution reductions, because other factors co-varied also. However, the evidence as a whole shows clear, immediate and sustained benefits to health from the interventions studied.

4.3.8. These results support in general terms the health impact assessment (HIA) work of the present study. However it gives only limited support to the specific HIA implementation that we have carried out. This is because in the intervention studies, the specific air pollution mixtures and health endpoints studied were different from those that were quantified in the present study.

4.3.9. Some direct comparisons are possible where the intervention studies examine mortality. Here, the intervention studies pointed to changes in health that are *greater* than would be predicted based on HIA using time series studies only. Thus they support the strategy of the present study – a strategy that some years ago was often questioned, but is now conventionally done in HIA work – of basing estimates of mortality principally on effects of longer-term exposure, as assessed via cohort studies. Because these mortality effects dominate the HIA work as a whole, it is particularly helpful to have some empirical evidence of the benefits of reduced pollution.

4.4 Economic Benefits of the Policies

4.4.1. The study has also quantified the economic benefits of the reduction in health and non-health impacts. The analysis shows extremely large benefits, as follows:

4.4.2. For the **road transport** sector policies, when compared to the 'no abatement' scenario, the monetisation of health and environmental effects lead to the following benefits:

- Annual benefits in the evaluation period (by 2001) are estimated at £462 million (central low estimate) to £2,746 million (central high estimate).
- By 2010, the annual benefits (undiscounted) are projected to rise to £924 million (central low) to £5,338 million (central high).
- The total benefits in the evaluation period (1990 – 2001) are estimated at £2,941 million (central low) to £18,370 million (central high). Note these benefits are from emissions in the time period 1990 – 2001 only. They do not include benefits from lower emissions in future years (post 2001) from a move to sustained new pollution levels.
- When the benefits in the entire relevant period of the study (1990 – 2010) are considered, the total benefits rise to an estimated £8,721 million (central low) to £51,510 million (central high).[76] Much greater benefits are projected to occur in the period 2002-2010, than have occurred in the period 1990 –2001, from policies in the road transport sector.

[76] The future health benefits in terms of life-year gained, from current pollution, have been discounted at 1.5%. For the present value data presented here, costs and benefits in 2003-2010 have been discounted at 3.5%. Again, these benefits are from emissions in the time period 2002 – 2010 only. They do not include benefits from lower emissions in future years from a move to sustained new pollution levels.

- The benefits are dominated by reductions in primary PM_{10}. In the uncertainty ranking, these have been given the highest confidence level (high). There are also significant benefits from lead reductions (again high confidence), but also nitrates (low confidence).
- Sensitivity analysis with other health impacts (included in many appraisals outside the UK) shows additional potential benefits of £352 million in 2001, and total benefits of £2,282 million in the evaluation period from 1990 – 2001.
- There are additional benefits from CO_2 reductions, relative to the no abatement scenario, of £15 million to £60 million in 2001, and total benefits of £42 million to £166 million in the evaluation period from 1990 – 2001. However, these cannot be attributed to the air quality policies.

4.4.3. For the **electricity sector**, when compared to the 'no abatement' scenario, the benefits of the air quality improvements achieved and projected are as follows:

- Annual benefits in the evaluation period (by 2001) are estimated at £1,316 million (central low estimate) to £5,589 million (central high estimate).
- These benefits exclude the effects on ecosystems (a very important omission given this was the main basis of the international agreements).
- By 2010, the annual benefits (undiscounted) are projected to rise to £2,122 million (central low) to £9,930 million (central high).
- The total benefits in the evaluation period (1990 – 2001) are estimated at £10,809 million (central low) to £50,608 million (central high). These are much higher than for the road transport sector. Note these benefits are from emissions in the time period 1990 – 2001 only. They do not include benefits from a move to sustained new pollution levels.
- When the benefits in the entire relevant period of the study (1990 – 2010) are considered, the total benefits (discounted) rise to an estimated £25,764 million (central low) to £120,402 million (central high). The benefits in the projected period (2002 – 2010) are only slightly greater than in the evaluation period (in contrast to the road transport sector – where the projected period dominates benefits)[77]. This reflects the fact that ESI policies have generally been more effective, relative to the no abatement scenario, in the evaluation period.
- The benefits are dominated by reductions in SO_2 from secondary PM_{10} as sulphates, and to a lesser extent, SO_2 as a gas (including non-health effects). The banding of impacts into sensitivity categories (high, medium, low) shows that the greatest benefits are associated with the medium confidence band, all from secondary PM_{10} as sulphates.
- We believe 38 to 100% of the ESI benefits above can be directly attributed to air quality policies.
- The additional benefits from CO_2 reductions in the ESI have been estimated at £665 million to £2,660 million in the evaluation period (to 2001), when compared to the 'no abatement' scenario, rising to £1,142 million to £4,568 million by 2010. The total CO_2 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[78]. These are much greater than for the road transport sector. Note the CO_2 benefits have occurred

[77] Again we stress these benefits are from emissions in the time period only. They do not include benefits from lower emissions in future years beyond 2010 from a move to sustained new pollution levels.
[78] 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 current review.

alongside the improvements in air quality, though they have not occurred directly as a result of air quality policies.

4.4.4. Note the numbers above do not include benefits from impacts not valued (particularly ecosystems). They only include benefits in the UK, and do not account for the benefits from the reduction in trans-boundary pollution that occurs in Europe, or the benefits in the UK from reductions in European emissions associated with the same legislation. They do not include the effects of NO_X emissions on ozone formation. They are therefore likely to represent a sub-total of overall benefits.

4.5 Economic Costs of the Policies

4.5.1. The study has estimated the costs of policies in the sector, looking at both the ex ante (predicted) and ex post (actual) costs.

4.5.2. For the **road transport sector**, 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 of the study (1990 – 2010). These are higher than our lower estimate of benefits above, but broadly similar to our higher estimate of benefits.

4.5.3. The total ex post costs of the policies are more difficult to estimate accurately. The ex ante data for the four Euro standards, in the evaluation period (1990 –2001) leads to extremely high estimated costs, totalling £12 to £19 billion for the UK. The ex post data that does exist indicates that the actual costs were lower, for example, an analysis of the underlying technical component cost to manufacturers indicates costs for Euro I of £0.5 to £0.9 billion in the evaluation period. It is difficult to estimate the ex post costs for all vehicles, from Euro I to IV technology (especially given the uncertainty over Euro IV technology), though we believe it could be below £4 billion, perhaps significantly so.

4.5.4. For fuel quality polices, it is clear that there is an additional cost to the refinery sector for upgrading facilities, a premium on the production of cleaner fuel (greater processing or more expensive feedstock), and the additional costs of storage, marketing, and distribution. All of these costs were predicted to lead to large increases in fuel prices ex ante. The ex ante costs indicate that the introduction of the three main fuel quality improvements (low sulphur diesel in 1996, and 2000 and 2005 fuel quality standards for diesel and petrol) would require very large investment, with estimated total costs of £250 million for 1996 diesel, £1255 - £1345 million for 2000 fuel quality, and £908 – 1089 million for 2005 fuel quality levels. There is also the additional cost of unleaded fuel. The predicted price rises from the four fuel quality policies, if passed through to petrol and diesel prices, would equate to additional costs of 2.5 pence/litre for diesel and 1.8 – 2.0 pence per litre for petrol, and would have led to ex ante costs in the evaluation period of £4 billion in the UK. However, the ex post costs for unleaded petrol indicates much lower values than predicted ex ante. Moreover, the ex post cost estimates of the investment costs for the sulphur policies indicate that these are also a significant over-estimate - certainly for 2005 fuel quality standard, but also for 2000 fuel quality standard.

4.5.5. In nearly all cases, the estimated ex ante costs have been higher than actually occurred (as seen in the ex post cost analysis). There appears to be a consistent over-estimation of ex ante costs of the all vehicle emission and fuel quality standards. Comparison of cost estimates of each standard (by technology cost per vehicle) indicates that ex ante estimates fell significantly over time in most cases. One reason for the lower out-turns appears to be that the costs of meeting successive policies in the road transport sector were not additive, but there has also been a tendency for over pessimistic assumptions for technical progress. Moreover, in many cases the ex ante costs are based on specific technical components, that in practice, the manufacturers did not need to fit to comply with new legislation. This pattern is matched by a review of US road transport policies, in terms of the ex ante costs and the ex post out-turns, for both fuel quality standards and vehicle emissions standards.

4.5.6. Overall, our analysis of ex post costs indicates that the actual out-turns are similar to the 'central low' estimate of benefits above, and much lower than the 'central high' estimate of benefits.

4.5.7. For the **electricity sector**, the analysis has shown that:

- There is a similar pattern of high ex ante costs predicted.
- For example, the ex ante costs of the first UNECE protocol forecast increases in generating costs of up to 30% and increases in electricity prices by as much as 25%. In contrast, an analysis of ex post electricity production costs and prices in the UK shows that costs/prices actually fell during the period.
- The total <u>ex ante</u> costs of the two UNECE protocols have been estimated £5,409 million (low) to £29,705 million (high) for the evaluation period (1990-2001). The total <u>ex post</u> 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
- A similar pattern has been found for recent appraisals, with the sulphur targets for the National Emission Ceilings Directive (for 2010). Three successive appraisals of the costs of this policy were undertaken during the last decade. They show that estimates fell substantially through the 3 series of analysis, with the earliest analysis giving costs roughly twice as large as a 1999 assessment, and about 10 times higher than the 2001 results.
- However, much of the reason for the lower ex post out-turns has been due to privatisation and liberalisation, and the impact of fuel switching in the ESI, rather than due to over-estimates, *per se*, of high ex ante costs. Indeed, the costs of some technology rose during the assessments.
- Despite the undoubted success of the actions in improving air quality in the ESI there is an important consideration - the nature of these measures (i.e. liberalisation) means that they cannot be repeated within the UK with similar effect.

4.5.8. The study has also assessed the unit costs estimates ex ante and ex post for technical abatement equipment in the electricity generation sector. Earlier ex ante estimates significantly over-estimate the actual ex post out-turns in most, but importantly not all, cases. More ex ante recent estimates have tended to be more accurate, though in some areas, e.g. low sulphur coal, the ex post costs have been significantly lower than predicted in relatively recent ex ante studies.

4.5.9. However, it would be wrong to assume that ex ante appraisal always overestimates costs. There are examples where the ex post technical costs are similar or even higher than that anticipated ex ante. An example is for the UK assessment of the emission ceiling directive, where the estimated technological costs rose during the assessments, for example, with later information showing *increased* costs of abatement, for example, for FGD. There are also a number of examples where the costs of overall policies have turned out to be much higher than anticipated. One such example is the European appraisal undertaken for the first air quality daughter directive. The reason for this error was not in the cost estimates, but in the air quality modelling analysis, which did not consider urban 'hot-spots'. Specifically, the methods used to determine the future concentrations of pollutants did not quantify levels appropriate to the legislation that was under consideration. This emphasises the need for adequate spatial (local) air quality modelling in such appraisal.

4.5.10. The study has assessed the reasons for some of the differences between ex ante and ex post costs. It is concluded that there are sometimes errors from the baseline predictions. There are also often omissions of measures that allow cost-effective reductions (options other than end of pipe, consideration of technological innovation, etc.). It is stressed that we have found no evidence of industry providing exaggerated cost estimates, but it is also clear that the costs that have been put forward by industry are usually based on pessimistic/'worst case' assumptions, or with a limited field of reference (i.e. without potential advances (learning), new measures, the fall of costs with large scale production, etc.). Note this also leads us to the conclusion that *legislation itself acts as a spur to research and innovation.*

4.5.11. The study has also investigated the wider economic impacts of air quality policy. The lack of ex post studies makes it difficult to draw robust conclusions on the extent of the wider economic effects that may have resulted from the imposition of the air quality policies.

4.6 Comparing Costs and Benefits of Policies

4.6.1. The ex ante and ex post costs of individual policies, along with the estimates of benefits (ex post) for the evaluation period are shown in the table below.

Summary of Ex Ante Costs, Ex Post Costs and Ex Post Benefits in the Evaluation Period for the Road Transport Sector (1990 – 2001)

	Evaluation Period (1990 – 2001) £ Million		
Policy	**Ex Ante Cost low to high**	**Ex Post Cost low to high**	**Ex Post AQ Benefit – Central low to Central high**
Unleaded petrol	£2590 M	£1036 M (though probably lower)	£357 M (L) £3662 M (H)
Euro I petrol cars	£5834 M £8751 M	£437 M £729 M	£1126 M (CL) £4922 M (CH)
Euro I diesel	£2273 M £2970 M	Not known	£702 M (CL) £4256 M (CH)
1996 low Sulphur	£561 M	Not known	£263 M (CL) £2409 M (CH)
Euro II all vehicles	£3197 M £6189 M	Not known	£329 M (CL) £1972 M (CH)
2000 fuel standards	£737 M	£ 368 M*	£36 M (CL) £329 M (CH)
Euro III all vehicles	£648 M £739 M	Not known	£42 M (CL) £213 M (CH)
2005 fuel in 2000/1	£270 M	£135M*	£68 M (CL) £500 M (CH)
Euro IV all vehicles	Not in evaluation period	Not available yet	£19 M (CL) £109 M (CH)
All Policies	**£16109 M** **£22807 M**	**Estimated £2000 M** **£4000 M**	**£2941 M (CL** **£18370 M (CH)**

Summary of Ex Ante Costs, Ex Post Costs and Ex Post Benefits in the Evaluation Period for the Electricity Sector (1990 – 2001)

	Evaluation Period (1990 – 2001) £ Million		
Policy	**Ex Ante Cost low to high**	**Ex Post Cost low to high**	**Ex Post AQ Benefit – Central low to Central high**
UNECE			
1st Sulphur Protocol	£4609 M to £28905 M	0 to £4818 M	£4334 M to £19813M (CL to CH).
2nd Sulphur Protocol	£800 M	0 to 29 M	£3079 M to £ 14078 M (CL to CH).
Environment policy			
Reduction in Fuel Oil "S" content	£55M to £125 M	Not known	£13 M to £59 M (CL to CH)
IPC			
Low sulphur coal	£484 M	0	£1246 to £5694 M (CL to CH)
FGD	£900 M	£935 M (excluding operating costs)	£1459 M to £6990 M (CL to CH)
Low NOx burners	£180 M	£83 M	£198 M to £1255 M (CL to CH)
Particulate abatement	Not estimated	Not estimated	£11 M to £73 M (CL to CH)
Renewables			
NFFO (all)	Not estimated	£600 M to 1999 Assume ~£900 M to 2001	£498 to £2336
All policies	**~£6,000M to ~£30,000 M**	**~£2000 M**	**£10809 M to £50608 M** **(CL to CH**

The values only include UK benefits. 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 because policies have different implementation dates, the absolute costs and benefits appear very different for different policies in the evaluation period. Note benefits are from emissions in the time period 1990 – 2001 only. They exclude benefits from lower emissions in future years (post 2001) from a move to sustained new pollution levels.

4.6.2. We make the following conclusions on the success of individual policies:

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

4.6.3. The analysis has also provided a number of other interesting conclusions:

- The marginal benefit per tonne of primary PM_{10} abated in the road transport sector has 50 times the health benefit of primary PM_{10} from the ESI. This is due to the high population exposed to road transport emissions, which are emitted at ground level, in extremely densely populated urban areas. This is an extremely important conclusion of this study – it shows that emissions from different sources can have very different impacts and has major implications for future air quality policy in achieving cost-effective improvements.
- 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 for 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), then this would increase the benefits of road transport sector policies overall very dramatically (even though it would reduce the benefits of road transport policies in 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 low, relative to the main effects already captured in UK appraisal.
- The economic benefits of the reductions in benzene, 1,3-butadiene, and benzo[a]pyrene are low (relative to other pollutants);
- 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 road 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);

4.7 Lessons for Future Appraisal and Research Recommendations

4.7.1. The conclusions of the study are presented below set in the context of the study objectives (section 1).

➢ *Have the policies been cost effective in achieving air quality improvements and consequent health and other benefits?*

4.7.2. It is clear that the policies in the road transport sector and the ESI have had a major impact in reducing air pollutant emissions[79]. They have also had a major effect in improving air quality and ensuring progress towards UK and European air quality standards or objectives. Finally, they have had extremely large benefits in reducing the health and environmental impacts of air pollution. A summary of the benefits has been presented in the earlier sections.

4.7.3. The study has not undertaken a comparative analysis for other policies or sectors, including other potential policies not implemented. 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 these air quality benefits have been achieved at low or even least-cost.

[79] Note no inferences should be drawn from the study about the relative effectiveness of instruments or policies beyond those explicitly covered in the study (or their potential application in other sectors. Without further analysis, it is not possible to conclude this also applies to the other sectors (particularly the industrial and domestic sectors), and so to the air quality strategy as a whole. Moreover, we highlight that the study has focused on the major policy initiatives in these sectors and we have not considered all measures introduced such as some Government programmes (such as wider marketing or information programmes).

➢ *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.*

4.7.4. The overall costs and benefits of individual policies have been assessed individually and in combination for both sectors. The economic costs and benefits are summarised in earlier tables in this chapter. Overall, the analysis shows a number of general trends:

- Firstly, there is a good justification (benefit to cost ratio) for the air quality policies implemented in both sectors, i.e. when comparing benefits to the 'ex post' cost out-turns. 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 (at least for the 'central low' estimate of benefits - the 'ex ante' costs in appraisals are usually similar to the 'central high' estimate of benefits estimated here). This is important, because it would imply that these policies might not have been justified on the basis of a cost-benefit analysis before the policies were introduced. [80]

This has some extremely important lessons for future policy appraisal (discussed later).

➢ *How do the costs made before the legislation was implemented (ex-ante) compare with actual costs after implementation (ex-post)?*

4.7.5. 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, and in many cases significantly so. However, we also have found some cases where ex ante costs were underestimated, including one example where the total costs of a major piece of air quality legislation was significantly underestimated.

➢ *Which policies have been successful and which have not?*

4.7.6. This was summarised earlier in the chapter. We have found that the fuel quality standards and earlier Euro standards have had most benefits in the road transport sector. In the electricity sector, we have found that the specific policies relating to increased use of natural gas, IPC, and later renewable subsidies had the best ratio of benefits to costs. For the first two of these policies, there is overlap with the UNECE sulphur protocols (discussed above).

➢ *What are the lessons for future air quality policy?*

4.7.7. 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

[80] In practice, earlier appraisals did not include full benefits analysis, and this issue did not arise

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)[81], 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[82]. 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 $\mathbf{SO_2}$ 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 $\mathbf{PM_{10}}$. 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

---

[81] There is some evidence of effects for long-term exposure, e.g. from the US, though there are problems distinguishing the effect of NO_2 from particles. Recent WHO guidance is therefore that the current 40 microgram/m^3 guideline value should be maintained or lowered.

[82] 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.

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 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 additional points have been raised from the uncertainty and sensitivity analysis undertaken. These are summarised earlier in this chapter (*point 4.6.3*).

➢ *What lessons are there for future appraisal? What information is needed to help inform the development of future air policy?*

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

4.7.9. **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.

4.7.10. 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 the cost-benefit analysis, the general assumption is that the cost estimates are far more accurate than the benefits analysis. The data in this study shows that this conclusion is rarely valid.

4.7.11. 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.

4.7.12. **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.

4.7.13. 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.

4.7.14. 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[83]. 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 will have a strong influence in determining whether future policies pass a cost-benefit analysis.

4.7.15. 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[84]. 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 analysis 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 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.

4.7.16. **Quantification of Benefits – Which Benefits.** The final lesson for future appraisal is in relation to the types of benefits included. There are four issues identified.

4.7.17. 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

[83] 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.

[84] For example, there are less risks if a bundle of pollutants are reduced, rather than focusing on one pollutant, however, such an approach is less efficient.

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 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.

4.7.18. 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.

4.7.19. 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 of emissions have been assessed over the same life-time, consistent with previous practice in appraisal[85]. However, in practice, the emissions benefits will continue for future years, after the capital costs of the plant have been recovered. This may lead to a situation where appraisal underestimates the full benefits from policies (i.e. because it leads to a sustained level of lower pollution for all future years).

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

4.7.20. Future air quality policies need to be strongly linked with greenhouse gas emissions reductions. This is important because the air pollution costs of the road 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.

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

[85] The simplest way to explain this is we assess the discounted benefits from a series of 1-year emission pulses over, for example, a 15 year life-time. Note for most benefits this is relatively simple. For years of life lost, the benefits from a 1-year emission pulse extend into the future. We have followed up with life tables until the population alive at the time of pulse have all died, then discounted back to an annual benefit.

- 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.