3 Electricity Generation Sector

3.1 Introduction

3.1.1. This chapter evaluates air quality policies that have been implemented over the past decade in the **Electricity Supply Industry (ESI).** As with the previous chapter, it assesses the policies in terms of their cost effectiveness in achieving air quality improvements and consequent health and other benefits. It also aims assesses the costs and benefits of policies to provide information on which policies have been successful and which have not.

3.1.2. The study has considered:

- The emission reductions of individual policies and combined policies, compared to *what would have happened in the absence of the policies*, the so called 'no abatement' scenario. This is based on the conditions in 1990, but takes account of the economic/activity growth over the period;
- The progress towards the UK/EC air quality objectives/limit values from these policies, compared to the 'no abatement' scenario;
- The health and non-health benefits achieved by the policies, including the monetary benefits, compared to the 'no abatement; scenario;
- The ex ante and ex post costs of the policies;
- The wider economic costs (ex ante and ex post) of the policies;
- The comparison of the costs and benefits of policies.

3.1.3. The study has considered a number of policies affecting the ESI. It is stressed that these are very different to those considered in the transport sector for two reasons:

- Firstly, policies in the ESI do not follow in a sequential order, as has occurred in the transport sector.
- Secondly, since 1990, the UK electricity sector has undergone a radical restructuring that has introduced competition in both generation and supply.

3.1.4. This makes it much more difficult to accurately assess the benefits of air quality policy in the ESI sector. Our approach has been to consider first all the air quality benefits in the sector since 1990, relative to the 'no abatement' scenario, irrespective of why these have occurred. We have then considered the likely contribution of individual policies, and tried to estimate the proportion of benefits that should be assigned to air quality policy. We have therefore considered all of the following types of policies:

- Energy policies, including electricity liberalisation, introduction of gas in the ESI, and renewables policy;
- European emissions and air quality policies (e.g. UNECE Sulphur Protocol, Large Combustion Plant Directive, Sulphur Content of Liquid Fuels Directive);
- National environmental or emissions policy (IPC implementation and the introduction of technology or techniques[37]).

[37] Note IPC requires the use of 'techniques', rather just technical abatement measures.

3.1.5. While this approach is a pragmatic one, it does involve a number of assumptions. In practice, individual policies might have led to larger emissions benefits in the absence of other policies. The results of the analysis of individual policies for the electricity sector should therefore be seen as indicative.

3.1.6. There are a number of potentially relevant policies that have not been considered here. These include the introduction of VAT on energy supplies, the UK Climate Change Strategy and the UK Emission Trading Scheme. The analysis also excludes the future EU greenhouse gas emission allowance trading scheme. Whilst these policies will have benefits for air quality, they are directed at reduction greenhouse gas emissions. Defra has undertaken other work to investigate the cost-effectiveness of these policies. We have also not considered some Government programmes (such as the Energy Efficiency programme, or wider marketing or information programmes) introduced in the sector.

3.1.7. The year 1990 was fixed as the starting point for the analysis for the study in the Invitation to Tender. However, it is noted that a number of significant measures affecting emissions were already planned or in place at this point in the ESI, for example in relation to market privatisation, international emission limits and European emissions legislation on combustion plants. The study has included these policies as part of the overall air quality evaluation, though the benefits analysis has only assessed the period post 1990.

3.1.8. The analysis for the ESI sector has been undertaken over the period 1990 – 2010. We stress that the data from 1990 – 2001 represents the estimated actual emissions, as recorded and reported in the National Atmospheric Emissions Inventory (NAEI, 2003), i.e. the **evaluation period**. We have undertaken an ex post evaluation on this data, and compared it to the expected ex ante predictions. The data for 2002 – 2010 is based on our current best estimate of the likely out-turn (i.e. in fact this is an ex ante forecast), i.e. it is projected. Where possible, all data has therefore been split into the period 1990 – 2001 (evaluation) and 2002 – 2010 (projected).

3.2 Policies in the ESI and Emissions Reductions

3.2.1. The policies that have been introduced in the ESI have led to a very dramatic change in the fuel mix in the UK, as well as to changes in fuel quality, improved generation efficiency, and higher levels of pollution abatement equipment. The individual policies, and their effects, are described below, split by policy.

Energy policies

3.2.2. ***Electricity Privatisation and Liberalisation***. During 1990, the public electricity supply industry in Great Britain was re-organised[38]. Privatisation and liberalisation led to a significant number of new entrants to the ESI during the decade, with electricity supply companies purchasing generating stations or acquiring interests in companies building new

[38] Prior to 1990, the industry comprised the Central Electricity Generating Board (CEGB), twelve area boards in England and Wales, the South of Scotland Electricity Board (SSEB) and the North of Scotland Hydro-Electricity Board (NSHEB). Following the Electricity Act, the CEGB was split into four companies, the twelve regional electricity companies replaced the twelve area boards, and in Scotland, three companies replaced the SSEB and NSHEB. In England and Wales, generators and suppliers traded electricity through the Electricity Pool, with Electricite de France and the Scottish generation businesses as external members of the Pool. Note in March 2001, the trading arrangements changed with the introduction of the New Electricity Trading Arrangements (NETA), based on bi-lateral trading between generators, suppliers, traders and customers.

power stations. It led to an increase in the efficiency of existing plant generation (shown below), and also a significant change in the fuel mix of new entrants. Note the increase in efficiency is clearly shown for nuclear generation, but is not as apparent for coal-fired efficiency, due to the changing way coal was used for generation towards the end of the decade (as coal became the marginal fuel for generation[39]).

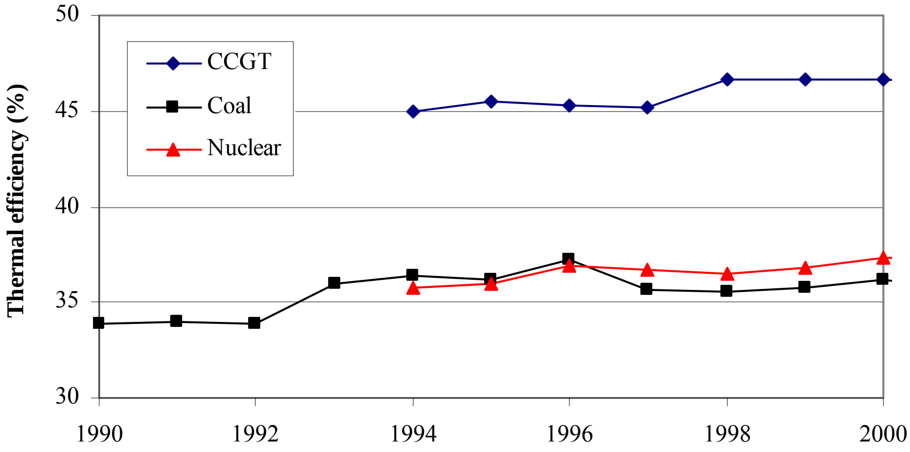


Figure 3-1. Thermal efficiency (gross calorific value basis).

Source: (1996 – 2001) DUKES, 2003. (1994 – 1996) DUKES 1999. (1990 - 1993 DUKES 1995)

*3.2.3. **Gas Use***. The use of gas for power generation started to emerge in the early 1990s and rose rapidly through the decade, the so-called 'dash for gas'. At the start of the decade, coal was the dominant fuel for electricity generation, followed by nuclear power and oil. By the end of the decade, the split between coal, nuclear and gas was approximately equal, shown below.

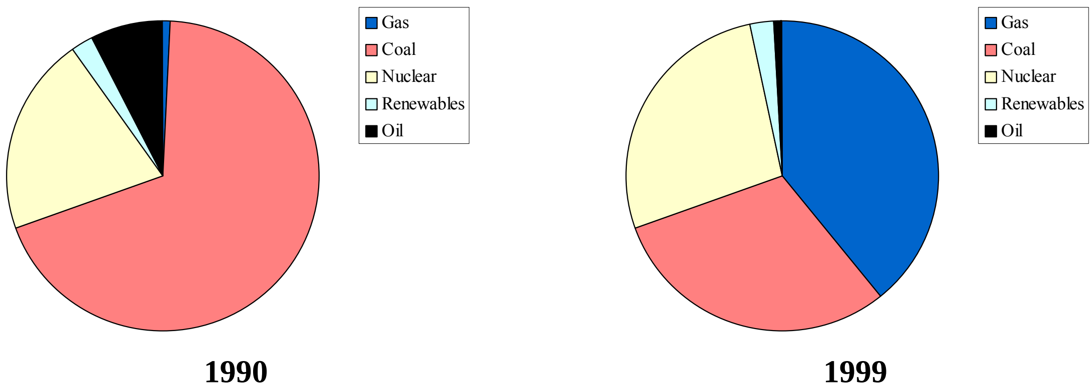


Figure 3-2. Electricity Supplied as a % by Fuel (Major Power Producers 1990 – 1999).

3.2.4. The rapid increase in gas was primarily due to two factors[40].

- Firstly the economic drive from market liberalisation. There was a strong incentive for new entrants and existing generators to use low cost gas supplies to develop new capacity, especially given technical advances had improved the economics of gas plant through the introduction of combined cycle gas turbines (CCGT), which increased thermal efficiency to about 55% compared to 35% for conventional plant.

[39] Note this trend was reversed in 2000, as coal generation increased. CCGT efficiency also dropped (slightly) at this time, due to less intensive use of gas (due to high gas prices).
[40] Other factors could also be said to have played a role in this policy change, including the coal miner's strike of 1984, and the political problems created by acid rain in Scandinavian countries.

- Secondly, increasing environmental legislation and controls (see policies below) favoured gas over coal fired generation, due to the additional costs of SO_2 abatement equipment needed for new coal fired plant.

3.2.5. Prior to the early nineties, gas was seen as a 'noble fuel', not to be used for electricity generation. However, in the early 1990s, many OECD countries lifted restrictions on the use of gas for generation. The UK government shifted towards such a policy during liberalisation and afterwards, by favouring gas over coal-fired plants in a 1993 White paper, which favourably compared the economics of CCGT gas-fired plant over coal. The 'dash for gas' continued throughout the decade until a temporary moratorium was imposed on gas-fired plants in 1997 - since lifted.

3.2.6. ***Renewables Policy (NFFO).*** In 1990 a new market support mechanism was introduced under the 1989 Electricity Act, known as the Non-Fossil Fuel Obligation (NFFO) in England and Wales, and the Scottish Renewables Obligation (SRO) and the Northern Ireland NFFO (NI-NFFO). One of the main justifications for NFFO was to address market imperfections, the most important of which was identified as the environmental externality from conventional fuels – see Box 3.1 below. These Obligations required the electricity supply companies in the UK to secure specified amounts of new generating capacity from non-fossil sources, including renewables (DTI, 2003). This renewables capacity was secured through contracts with renewables generators at premium rates, with the difference between the market and premium price paid for by the Fossil Fuel Levy on retail electricity bills.

3.2.7. Successive Orders in England and Wales distinguished between technologies by allowing different price premiums for electricity generated, and by supporting different levels of new capacity from each technology. These price differentials allowed individual technologies to be encouraged in a way that was appropriate to their relative stage of commercialisation. Electricity prices supported under consecutive Renewables Obligation Orders were required to converge with prices of electricity from conventional generation, and new renewable projects therefore had to be the most cost-efficient schemes available. This was achieved by requiring potential renewable generators to compete for contracts, with the schemes offering the lower bid prices being awarded contracts. Although the selection of projects ensured that no single technology or contractor could dominate an Order, the major beneficiaries of NFFO overall have been energy from waste (landfill gas and MSW combustion) and onshore wind power projects. The net result of renewable support policies has been a steady increase in the proportion of renewables for generation in the UK, shown in the Figure below.

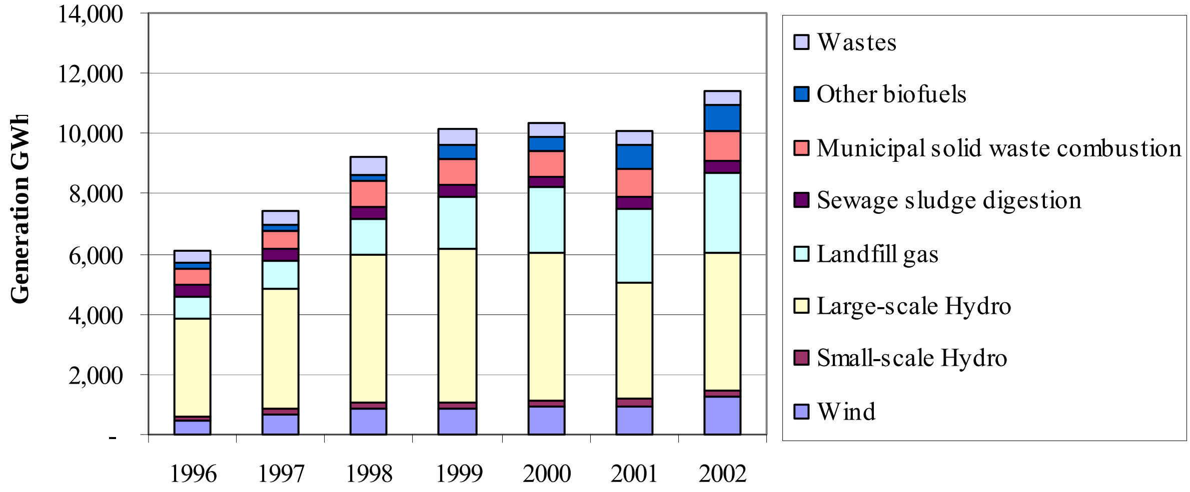


Figure 3-3. Renewable Generation in the UK.

Source: DUKES, 2003.

Box 3.1. The Aims of Renewable Policy

The NFFO programme was introduced because renewable technologies were still immature and needed further development and demonstration to be able to compete with established fuels. The aims of the programme, prior to introduction (i.e. in appraisal), included:

- To encourage the uptake of technologies that were approaching competitiveness (including to identify and remove inappropriate legislative and administrative barriers).
- To stimulate, in collaboration with industry, the development of technologies that were likely to become competitive in the short to medium term.
- To assess and maintain technologies that had prospects for the longer term, for the option of developing and deploying at a later stage.
- To encourage internationally competitive industries to develop, and utilising capabilities for the domestic and export markets.

NFFO also had a number of specific policy objectives:

- To encourage technology uptake and stimulating technology development in partnership with industry.
- To promote the development of internationally competitive industries to exploit the domestic and export market for new and renewable energy technologies,
- To address market imperfections.

Around six market imperfections were identified, however, the primary one was the presence of environmental externalities, which artificially reduced the market price of conventional energy sources (i.e. competing technologies did not meet the cost of abating the environmental pollution they caused and were able to offer energy at prices which excluded these costs).

An evaluation of the new and renewable energy programme[41] (SPRU, 1999) found NFFO and the supporting programme had been successful in encouraging the uptake of renewable energy, very little of which would have occurred in the absence of support. It also found that a market in renewable energy had been established with a significant number of participants; and there was an improvement in the availability of finance for investment. However, the evaluation also found that the programme had been less successful in developing a UK renewables technology industry to supply domestic and export markets.

3.2.8. In April 2002, the ***Renewables Obligation*** was introduced. This requires all licensed electricity suppliers in England & Wales to supply a specified and growing proportion of their electricity sales from a choice of eligible renewable sources (DTI, 2003). The Renewables

[41] Evaluation of the DTI New and Renewable Energy Programme. 1994-8 Final Report. SPRU (1999).

Obligation Scotland is the equivalent instrument in Scotland. Suppliers are responsible for demonstrating that compliance to OFGEM through a system of Renewables Obligation Certificates (ROCs). The Obligation is the key policy mechanism by which the Government is encouraging the growth necessary to reach the UK's renewable energy targets - by 2010, 10% of the UK's electricity should be supplied from renewable sources[42].

UK and European Emissions and Air Quality Policies

3.2.9. The first major environmental legislation affecting the UK ESI was the ***UNECE Protocol*** (United Nations Economic Commission for Europe Convention on Trans-boundary Air Pollution (UNECE CLRTAP)). Concerns over acidification in the 1980s led to the establishment of a series of protocols that set emission ceilings[43] for different pollutants to be reached by specific dates. The **First Protocol on the Reduction of Sulphur emissions** was adopted in Helsinki in 1985, and has been in force since September 1987. This protocol required a 30% cut in sulphur emissions or the trans-boundary fluxes by 1993, against a 1980 baseline[44]. The Protocol concerning the Control **of Emissions of Nitrogen Oxides** was adopted in Sofia in October 1988 and has been in force since February 1991. The principal obligation of the protocol was to reduce emission of Nitrogen oxides or their trans-boundary fluxes so that emissions at the end of December 1994 did not exceed the emissions for 1987. As with the sulphur protocol, there was also a common understanding that the target would not be exceeded in the following years. The **Second sulphur protocol**, the 1994 Oslo Protocol on Further Reduction of Sulphur Emissions, entered into force in August 1998. This included a differentiation of emission reduction obligations of different Parties (due to an effects-based approach). In signing up to the UNECE 2nd Sulphur Protocol, the UK agreed to achieve a reduction of at least 80% of its national annual emissions of sulphur dioxide by 2010, compared with 1980 levels. This target was to be achieved through intermediate reductions of at least 50% by 2000 and 70% by 2005. The plans for meeting this objective were set out in the UK's sulphur reduction strategy.

3.2.10. ***The UK Sulphur Strategy.*** The government's sulphur strategy[45], which was published in December 1996, set out the strategy for meeting the 2nd UNECE sulphur protocol. It discussed the means for delivering the target reductions, looking at the move from industrial burning of coal and heavy fuel oil to gas, the completion of a programme of fitting FGD at power stations, and the requirement for industrial processes to use BATNEEC under IPC (see later paragraph). The document recognised that the factors above converge most significantly for power stations. The strategy indicated that the 2000 and 2005 targets would be delivered by the upgrading of industrial combustion plant in the UK and that compliance with the 2010 target was almost assured on the basis of IPC (though there was some margin to undershoot the targets). It also foresaw additional advances in technology and control techniques that would result in further improvements. In 1996 a declining cap on overall emissions of SO_2 from the coal and oil-fired power stations was established by the

[42] In the recent energy white paper, this target was increased to an ambition to double this to 20% by 2020. A recent announcement increased the target share to 15.4% by 2016 as an interim target.

[43] National 'Emission Ceilings' are the maximum amount of a pollutant that a country is permitted to release over a defined period, typically a year. The use of ceilings, derived through consideration of cost-effectiveness, gives Member States the opportunity to define their own strategies for attainment, reflecting national priorities and circumstances. Two bodies are active in setting legislation of this type in Europe, the EU and the UNECE. EU Legislation covers its Member States. UNECE's CLRTAP apply to all European countries that ratify.

[44] Note the UK refused to accept the 30% reduction required under the UNECE's first sulphur protocol (and as a result, the UK government of the 1980s earned the country the title of "The Dirty Man of Europe").

[45] Reducing National Emissions of Sulphur Dioxide: A Strategy for the United Kingdom, 1996.

Environment Agency, with an overall emission of 365 kilo-tonnes SO_2 to be achieved in 2005 (England and Wales only). These reductions, shown in the table below, were achieved by operators switching to gas and a gradual reduction in fuel sulphur content.

Table 3-1. Emission ceilings for SO_2 for coal and oil-fired power stations in England and Wales (from the UK Sulphur Strategy).

Calendar year	1997	1998	1999	2000	2001	2002	2003	2004	2005 +
SO_2 (kt)	1500	1500	1010	892	738	529	505	426	365

3.2.11. ***Integrated Pollution Control (IPC)***. The IPC regime, introduced under Part I of the Environmental Protection Act 1990, applied an integrated approach to the environmental regulation of major industrial activities. Emissions to air, water and land were considered together. IPC requires operators to use BATNEEC (Best Available Techniques Not Entailing Excessive Costs) to prevent, or where that is not practicable, to minimise and render harmless releases from their process. The term techniques includes not only the application of technology such as the introduction of low NOx burners but also good management in the form of preventive maintenance; proper operation and supervision of processes (including associated pollution control equipment); proper training and instruction of all staff; good housekeeping; and minimising pollution that might arise during delivery, storage and handling of materials. IPC led to significant improvements in pollution control for power stations (notably coal and oil fired stations). The model was adopted by the EC under the 1996 IPPC (Integrated Pollution Prevention and Control) Directive (96/61/EC), and this will replace the IPC regime.

3.2.12. The Environment Agency implemented IPC through process authorisations and updates (variations). This led to the increased use of abatement equipment on fossil fuel plants and other measures, including:

- ***Particulate abatement*** (ESP, Filters and Cyclones). A 1996 variation notice varied the conditions (authorisation) to operate a combustion process for particulate controls, and required coal and oil-fired power station operators to meet a particles limit of 50mg/m^3 by 1st January 2001 and FGD fitted stations to meet 25mg/m^3 by the same date. This has had a significant impact in reducing emissions of PM_{10} from the ESI. Note these emission reductions can be entirely linked to IPC and best available techniques – there is no other legislation drivers that are relevant for this pollutant.
- ***Low-NO_X Burners*** (LNB) for NO_X. These were fitted to coal and oil fired plant between 1991 and 1999 and have led to major reductions in emissions of NO_X from these plants[46]. The introduction of these abatement measures is due to IPC, though there is other legislation (e.g. the UNECE NO_X protocol), which could be considered relevant.
- ***Flue Gas Desulphurisation*** (FGD). This was fitted to coal fired plant to reduce emissions of SO_2. FGD has a significant impact on emissions of SO_2 (it also leads to a reduction in PM_{10} emissions). The Drax and Ratcliffe power stations were fitted with FGD – coming on line over the period 1992 – 1995, with both stations fully fitted by 1995. Note more FGD is to be fitted to the remaining coal fired power stations in the UK in the coming years. We consider that IPC was the principle driver for the introduction of FGD.

[46] A number of coal stations have low NO_X burners - these are not necessarily successful and the Agency has not forced the issue to get the second half of Drax updated for example. Gas turbines do use low NO_X systems, though not all plants are fitted with them. Note the LCPD will change the requirements for existing plant.

- ***Low sulphur fuel***. The 1996 Variation Notice also requires operators to submit a case if they wish to burn coal greater than 1.2% without FGD beyond September 2001. It requires an upper limit of 1% on sulphur in fuel oil burnt in the boilers by 1/1/2003 (consistent with the sulphur content of liquid fuels directive – see below).

3.2.13. The 1996 Variation Notice also introduced a cap that limited emissions of SO_2 from coal and oil-fired power stations in England and Wales to 365 kt, to be achieved in 2005, and introduced a system of "A" and "B" limits. "A" limits were set on a site-specific basis to protect the local environment. "B" limits were intended to control the impact of groups of stations on the wider environment. In 2000 the authorisations were revised again, to include the requirement for stations to meet Air Quality Strategy objectives by 2005. The variation also revised the system of B-limits in order to encourage further construction of new FGD plants and higher utilisation of existing FGD plants, whilst facilitating market competition in electricity sales between generators that operated coal-fired power stations. The B limits operate a flexibility allowance system to take account of the potential for generators to gain market share from each other whilst limiting the scale of the allowances over the long-term to ensure broad environmental neutrality. They also require individual generators to run their FGD power stations ahead of their non-FGD stations, and to allow controlled flexibility in B-limits to those who achieve a load factor on their FGD stations double that on their non FGD stations.

3.2.14. The ***European Commission Large Combustion Plant Directive*** (LCPD) set limits in 1988 for emissions of SO_2, dust and NO_X for new power stations burning solid, liquid or gaseous fuels with a thermal input of over 50 MW. This had a major impact on the economic attractiveness of new coal plant, because it required costly abatement equipment. The Directive was recently revised (2001). This revision tightened the limits for new large combustion plant within the EU and, perhaps more significantly, also set emissions limits for existing power stations. However, the revised Directive states that for these existing plants (i.e. those in operation pre-1987), Member States could choose to meet the obligations by either complying with the set Emissions Limit Values (ELVs) for NOx, SO_2, and particles, or operating within a 'National Plan', set an annual national level of emissions calculated by applying the ELV approach to existing plants[47]. Following a recent consultation, Ministers considered that the UK should adopt the national plan approach (DEFRA, September, 2003) though this is a provisional decision. The potential impact of the revised LCPD on the UK generating mix is unclear, but could be very significant, especially when combined with other factors, such as the EU greenhouse gas emission trading scheme. Note the consideration of greenhouse gas reduction policies is not within the remit of this study, and there is insufficient information to allow a considered analysis of the revised LCPD in 2008 onwards.

3.2.15. The ***Sulphur Content of liquid fuels Directive*** (1999) introduced a limit on heavy fuel oil sulphur content to 1% by 2003 and 0.1% for gas oil by 2008. This was transposed in June 2000, as Sulphur Content of Liquid Fuels (England and Wales) Regulations 2000. The EC Directive does not affect the values shown for the evaluation period but there were some moves to lower S fuel in 2001. The UK did not implement any policies with respect to the S content of solid fuel. However, there was pressure through IPC for operators to use lower S content coal, which was achieved mostly through greater use of imported coal.

[47] Note, as an alternative to meeting the ELVs or being included in a National Plan, operators of existing combustion plants can commit to close the plant within 20,000 operational hours starting from 1 January 2008. This derogation has an end date of 31 December 2015.

3.2.16. The 2001 ***National Emissions Ceiling Directive***[48] provides for the introduction, by the end of 2010 at the latest, of national emission ceilings for pollutants causing acidification and eutrophication and for ozone precursors: sulphur dioxide (SO_2), nitrogen oxides (NO_x), volatile organic compounds (VOC) and ammonia (NH_3). The Directive is part of the follow-up to the European Commission's communication on a strategy to combat acidification. Recent projections for emissions of the four pollutants, taking other policy measures into account, show that the UK is on target to meet the ceilings by 2010 (though additional measures may be required to meet the SO_2 target, depending on how the revised LCPD is implemented). Parallel to the development of the EU NEC Directive, the EU Member States together with Central and Eastern European countries, the US and Canada have negotiated the new "multi-pollutant" protocol under the Convention on Long-Range Transboundary Air Pollution (the so-called Gothenburg protocol, agreed in November 1999). The emission ceilings in the protocol are less ambitious than those decided by the Council and Parliament.

Interaction between energy and air quality policy

3.2.17. The combination of all the above energy and environmental policies has led to a very dramatic change in the fuel mix in the UK over the evaluation period to 2001. This will continue further over the projected period to 2010. This has led to a dramatic reduction in emissions from the ESI and the associated air pollution (see next section). In the following sections we assess the benefits of the total improvement in emissions and air quality for the sector, and also assess the impact specifically of air quality policy.

3.2.18. At first glance, it may seem odd to include the analysis of energy policies alongside air quality policy, as in the above discussion. It is clear, for example, that the efficiency gains from privatisation and liberalisation are not related to air quality policy. However, for other energy policies there are interactions.

- While the dash for gas was primarily driven by the economic attractiveness of natural gas plant (low capital costs, quick build times), it was helped by the air pollution policies that required expensive abatement equipment on new coal plants (LCPD) and increasing pressure to reduce emissions from existing coal plants (UK Sulphur Strategy and IPC). Furthermore, without the ‘dash for gas’, other action would have had to be taken in the UK ESI to meet the international commitments agreed under the UNECE protocols.
- There is also a link between air quality policy and renewables. While NFFO was not specifically introduced to improve air quality, one of the primary aims was to address environmental externalities from conventional plant. At the time of introduction (1990), air pollution emissions were the primary environmental driver.

3.2.19. There are therefore ‘convergences’ between energy and air quality policies, which have led to the actual out-turn seen in the sector. This makes it extremely difficult to accurately allocate emissions improvements between policies. Our approach has been to assess individual measures introduced in the sector, and then assign these to policies. Where more than one policy is involved, we have presented our analysis as a range, reflecting the minimum and maximum benefits that can be attributed to individual policies

[48] Directive 2001/81/EC of the European Parliament and of the Council of 23 October 2001 on national emission ceilings for certain atmospheric pollutants [Official Journal L 309 of 27.11.2001].

Analysis of the 'without policies' scenario

3.2.20. It is also difficult to accurately construct a 'no abatement' scenario for the electricity generation sector, i.e. to assess *what would have happened in the absence of policies*? There are three main reasons for this.

- Firstly, the start of the evaluation period (1990) matches a time of major change in the ESI, and in fact a number of the policies were actually already in place including the process towards privatisation and the first UNECE protocol. We have considered these policies within the current study.
- Secondly, a large number of alternative scenarios are possible, which could have a major impact on the emissions out-turn. For example, scenarios with and without market liberalisation, with or without the UNECE sulphur limits in place, etc.
- Finally, in the absence of policies, there would have been a change in the price of electricity and therefore (potentially) a change in demand. For the transport analysis in the previous chapter, the study concluded that successive air quality policies do not appear to have led to any significant change in the prices of new vehicles or fuel to consumers. It is therefore acceptable to assume that in the absence of policies, transport activity would be similar to the actual out-turn. It is clear that for the electricity sector, certain policies, noticeably liberalisation, would have dramatically affected electricity prices. This would clearly have had some effect on demand and also on preferred generation technology.

3.2.21. The last point is particularly important. However, it was not within the study terms of reference to model the effects of a 'without policies' scenario on electricity prices, nor the impacts of individual policies on prices. A recent study has looked at some of the relevant issues for such an analysis, with work on electricity elasticities in the UK[49]. The analysis has looked at the response of energy demand to changes in fuel price, with demand changes measured for 2000, 2010, and 2020 from a change in 1996. The study shows differing elasticities to changing electricity prices in the domestic and industrial sectors, with different response in the short and long run. However, further modelling work would be needed to properly assess the short and long term effects for our 'without policies' scenario. By effectively ignoring these effects, we have assumed that there would be no short and long run change in electricity prices from the different fuel mix present in the 'no abatement' scenario. The impact of this is that we may under- or over-estimate the total kWh in our 'without policies' scenario. We highlight that this is a major uncertainty in the analysis presented[50].

3.2.22. The 'without policies' scenario (the 'no abatement') is therefore based on electricity demand changes over the evaluation period, and projected through to 2010. This is shown in the figure below.

[49] Elasticities in EM 4 version of DTI Energy Model. DTI. The modelling undertook a base run, where fuel prices were fixed at their 1995 levels. Output is assumed to grow in line with the DTI central low scenario assumptions. The response of energy demand to changes in fuel price are calculated by changing each price in turn by 10% upwards and downwards.

[50] However, the error from this assumption may be lower than first appears. The 'without policies' scenario has no environmental policies that would affect coal (such as LCPD or IPC), and also assumes that liberalisation would not have occurred. Existing and new coal plant would not require abatement equipment, and would be able to operate at costs that might be similar to CCGT (indeed coal generation without abatement is cheaper than natural gas when high gas prices occur). There is therefore no reason why electricity prices would not have remained stable, or even fallen as generation efficiencies increased for coal plant as technology improved. Moreover, the DTI study above showed that electricity's short run response to its price was zero (though the long run cost was not), and so any price changes might actually have low impacts on electricity demand out-turns.

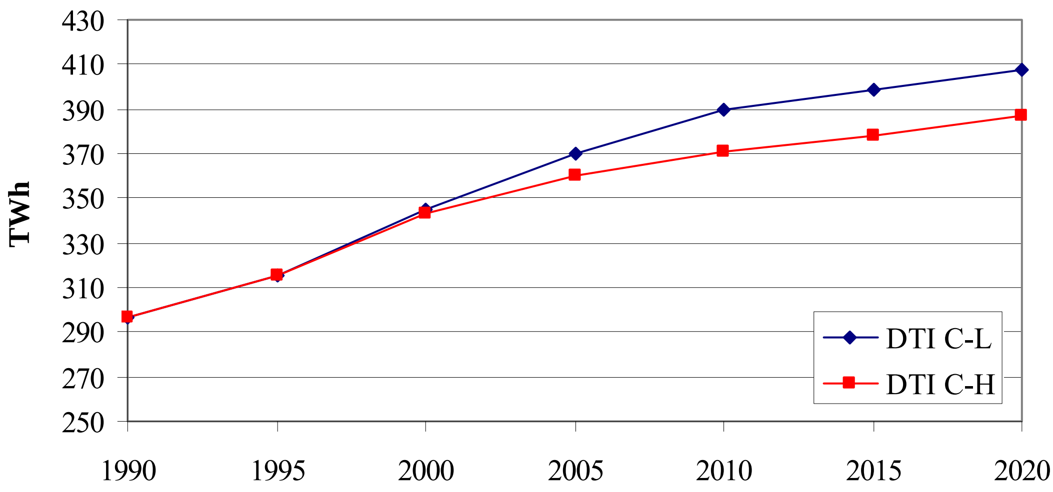


Figure 3-4. UK Electricity Demand (Electricity Supplied)

Source: EP68 (DTI)

Note DTI predictions are presented for different scenarios. The two central scenarios, the central low and central high, are used here. Note we have also used the terminology of a 'central low' and 'central high' to present our valuation range. We stress that the two are not linked, so that any discussion of a central low or central high in the results refers only to the range around valuation.

3.2.23. The study has undertaken a number of limited sensitivities around the 'without policies' scenario. This includes the construction of several 'no abatement' scenarios, including:

- Extrapolating the 1990 fuel mix forward in time through the entire evaluation and projected period, based on the actual increase in demand shown in the figure above (i.e. with no 'gas' in the fuel mix and no price effects).
- As above, but taking into account the efficiency improvements that have been achieved over the time period (again with no 'gas' in the fuel mix and no price effects).
- A number of additional sensitivities looking at assumptions about nuclear generation (assuming no nuclear growth post 1990 and based on actual nuclear output over time).

3.2.24. For the main analysis, we have considered the first two of these scenarios. This has the effect of only considering energy policies with some environmental convergences (i.e. the dash for gas and renewables). Because of the above issues with the analysis, notably price effects, the results below should only be seen as indicative.

3.3 Emission Reductions and Air Quality Benefits

3.3.1. The emission reductions[51] in the UK ESI from the introduction of all the above policies (all energy and environmental policies) is presented in the Figure and Table below. The data and emissions for the period 1990 –2001 are based on actual (historic) analysis. The data and emissions for the period 2001-2010 are based on forecast emissions reductions[52]. The figures show the extremely high emissions reductions achieved over the past decade. It also shows

[51] Note in all following sections, the ESI refers to the Major Power Producers only.

[52] We stress that this analysis was consistent with the best available information at the time and was based on the 2001 NAEI inventory. The emissions baseline for ESI has subsequently been updated.

these emissions reductions are predicted to continue through to 2010. The reductions are even greater when compared to the 'no abatement' scenario, due to the increase in electricity demand over the period. We stress that in practice, the emissions reductions of the policies extend beyond the end of the projected period (i.e. post 2010).

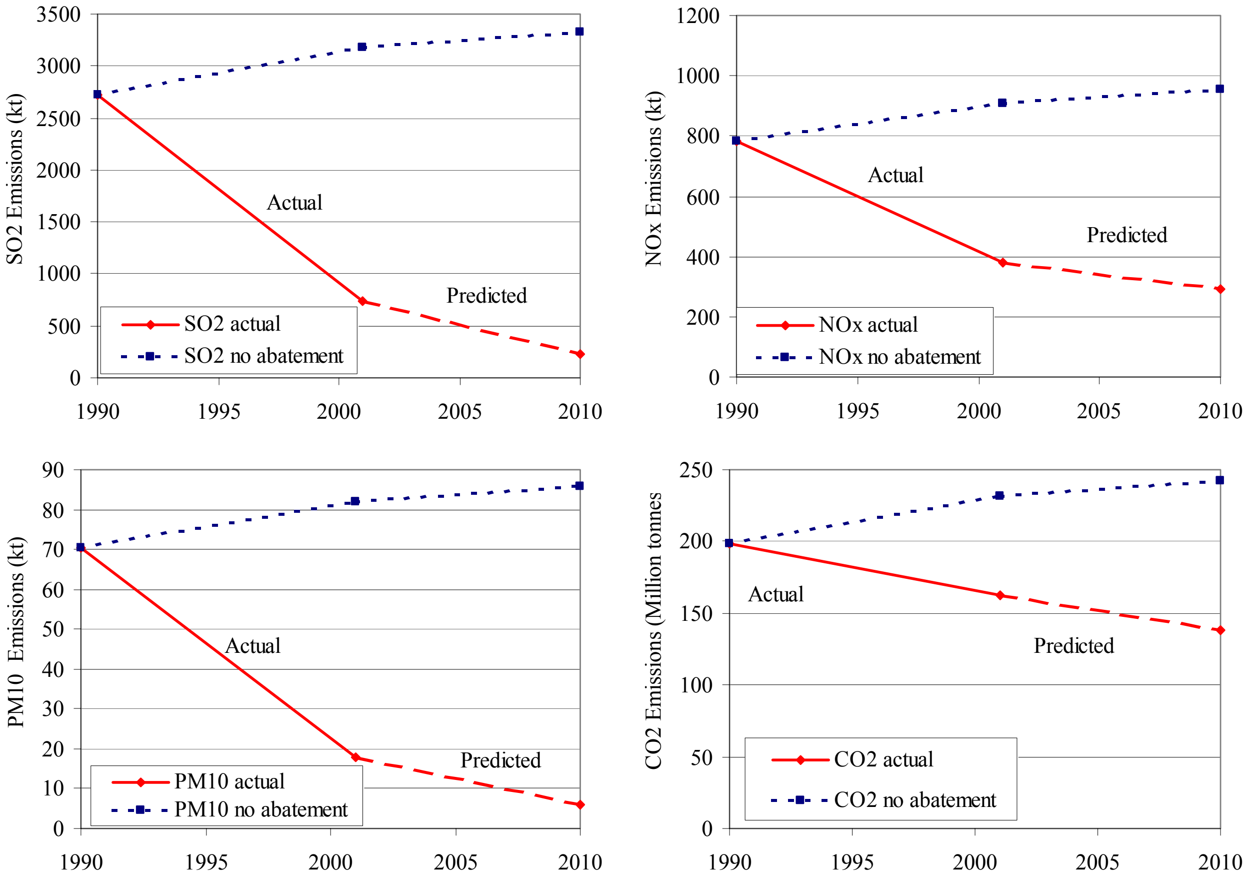


Figure 3-5. SO_2, NO_X, PM_{10} and CO_2 Emissions from the Electricity Generation Sector from <u>All</u> Policies within the Evaluation Period (1990 – 2010) and Projected 2002 – 2010 and for the 'Without Policies' (No Abatement) Scenario

3.3.2. The conclusions are that:

- The greatest emission reductions (against a 'no abatement' scenario) have been achieved in reducing SO_2 and PM_{10} emissions, with a 77% reduction against the 'no abatement' scenario in the evaluation period (by 2001) for both these pollutants. There are continued projected falls after this date, so that by 2010, there is a predicted 93% reduction for both these pollutants relative to the 'no abatement'. The largest emissions reductions have therefore occurred in the evaluation period.
- There are also large emissions reductions for NO_X with a 58% reduction in the evaluation period (by 2001) and a predicted 69% reduction by 2010.
- For the main air pollutants, the largest emissions reduction has occurred in the evaluation period. These improvements have been achieved against a background of increasing electricity demand.
- The policies have also had a large effect in reducing carbon dioxide (CO_2) relative to the 'no abatement' scenario, with a 30% reduction relative to the 'no abatement' scenario in the evaluation period (2001) and a projected reduction of 43% by 2010. There has also

been a reduction in absolute levels relative to 1990 – the base year for the international commitments on greenhouse gas emissions. The combination of all policies has led to a 18% reduction on 1990 emissions by 2001, and a predicted reduction of 31% on 1990 emissions by 2010. This is a very different effect to the transport sector, where there was almost no CO_2 reduction from polices implemented.

- The reduction in emissions between 1990 and 2001 shows a 'de-coupling' between emissions and electricity demand.

Table 3-2. Emissions from Major Power Producers in the Evaluation Period (1990 - 2001) and Projected by 2010, and for the Without Policies ('No Abatement').

Baseline				**% Change**	
Pollutant	**1990**	**2001**	**2010**	**1990 - 2001**	**1990 - 2010**
SO_2 (kt)	2723	743	233	*-73%*	*-91%*
NO_X (kt)	781	379	292	*-51%*	*-63%*
PM_{10} (kt)	70	18	6	*-75%*	*-91%*
CO_2 (kt)	198503	162634	137867	*-18%*	*-31%*
Electricity (index)[53]	100	116	122	*+17%*	*+22%*
No Abatement					
Pollutant	**1990**	**2001**	**2010**		
SO_2 (kt)	2723	3173	3327		
NO_X (kt)	781	910	954		
PM_{10} (kt)	70	82	86		
CO_2 (kt)	198503	231298	242547		
% Change in Emissions Actual against 'No Abatement'					
Pollutant	**1990**	**2001**	**2010**		
SO_2 (kt)	*0%*	*-77%*	*-93%*		
NO_X (kt)	*0%*	*-58%*	*-69%*		
PM_{10} (kt)	*0%*	*-78%*	*-93%*		
CO_2 (kt)	*0%*	*-30%*	*-43%*		

Note 2010 air quality and CO_2 emissions are based on the previous DTI central high scenario.

Note emissions reductions include effects of environmental policy, natural gas use and renewables.

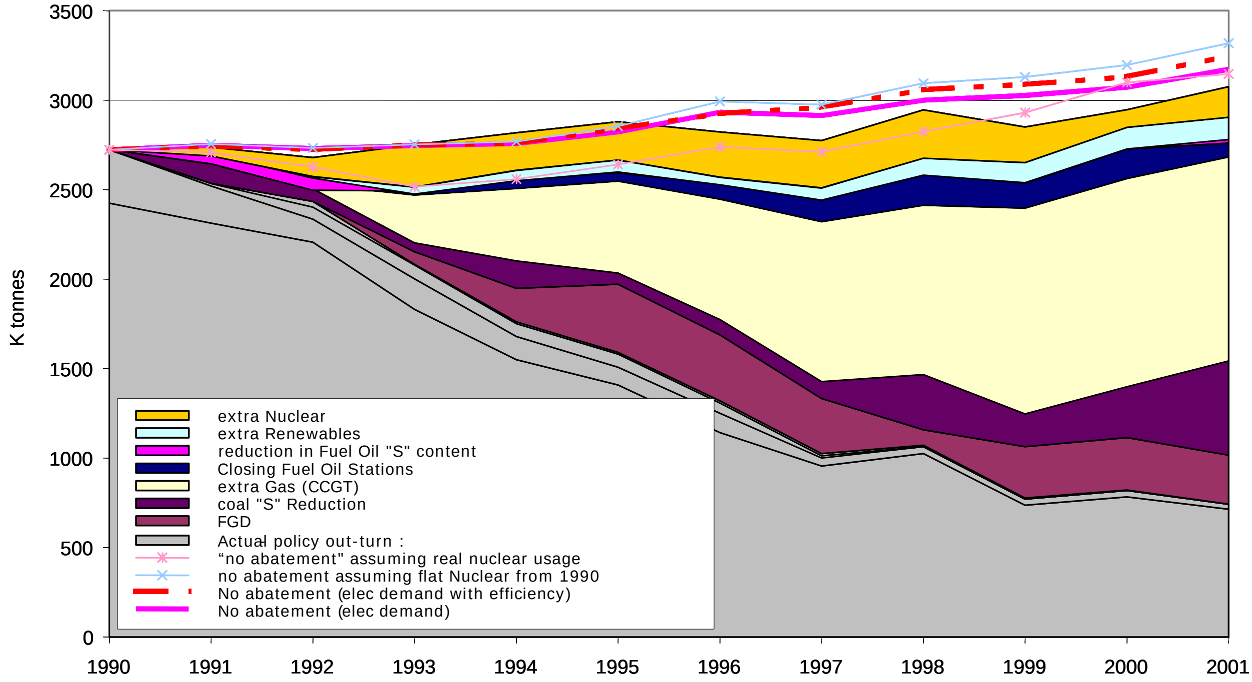
3.3.3. The analysis has also assessed the emissions reductions of individual policies. This is more difficult, due to problems outlined in the previous section. Our approach has been to assess the emissions reductions from specific *measures* or *technologies*, and then allocate these measures to specific *policies*. We have also looked at the reductions of specific policies or targets in isolation (e.g. the UNECE protocol), irrespective of the actual measures that may have led to these policies being achieved. The table below shows the allocation between measures and policies.

[53] The change in total UK electricity demand since 1990 (1990 = 100)

Table 3-3. Link between Measures (e.g. technical option) and Policies.

Measure	Policy
Increased renewables	NFFO/ Renewables Obligation
Increased gas use	Electricity Liberalisation EC Large Combustion Plant Directive UNECE sulphur Protocols The UK Sulphur Strategy Integrated Pollution Control
The introduction of sulphur abatement equipment for coal stations (FGD)	UNECE sulphur Protocols The UK Sulphur Strategy Integrated Pollution Control Large Combustion Plant Directive (future)
Lower sulphur content coal	Integrated Pollution Control
Lower sulphur content oil	Sulphur Content of liquid fuels Directive (2003)
Low NO_X burners	Integrated Pollution Control (in future years, new plant also affected by LCPD)
PM_{10} abatement equipment to coal/oil stations	Integrated Pollution Control (in future years, new plant also affected by LCPD)

3.3.4. The emissions out-turn for different measures are presented for SO_2 below, relative to the ‘no abatement’ scenario. The (top) graph shows that the main measures that have led to emissions reductions has been the switch to natural gas, the introduction of FGD, and in later year, the growing use of low sulphur coal. We have also undertaken an analysis to show the emission reductions of individual policies more clearly – this has looked at the actual emission out-turn and then removed the individual measures one at a time (bottom graph). This shows how far above the actual out-turn the emissions of SO_2 would be without the specific measure (note the higher the line on the graph, the better the emission improvement of the measure).



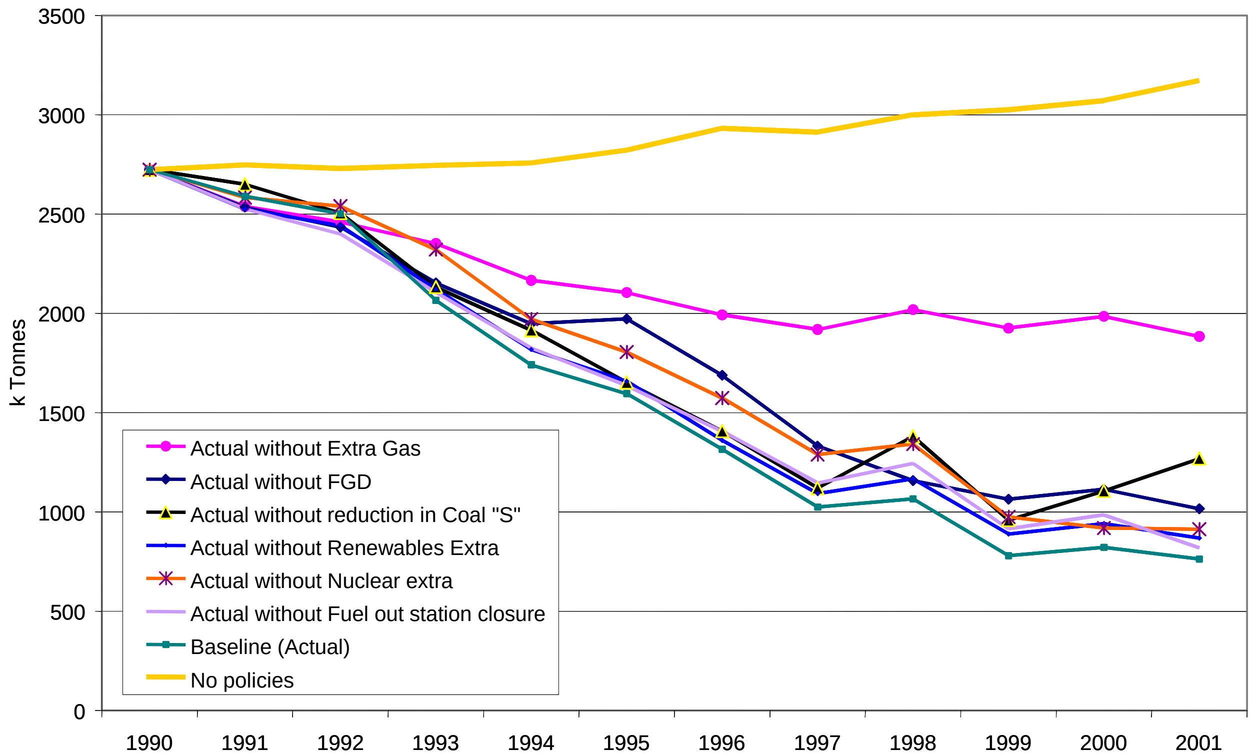
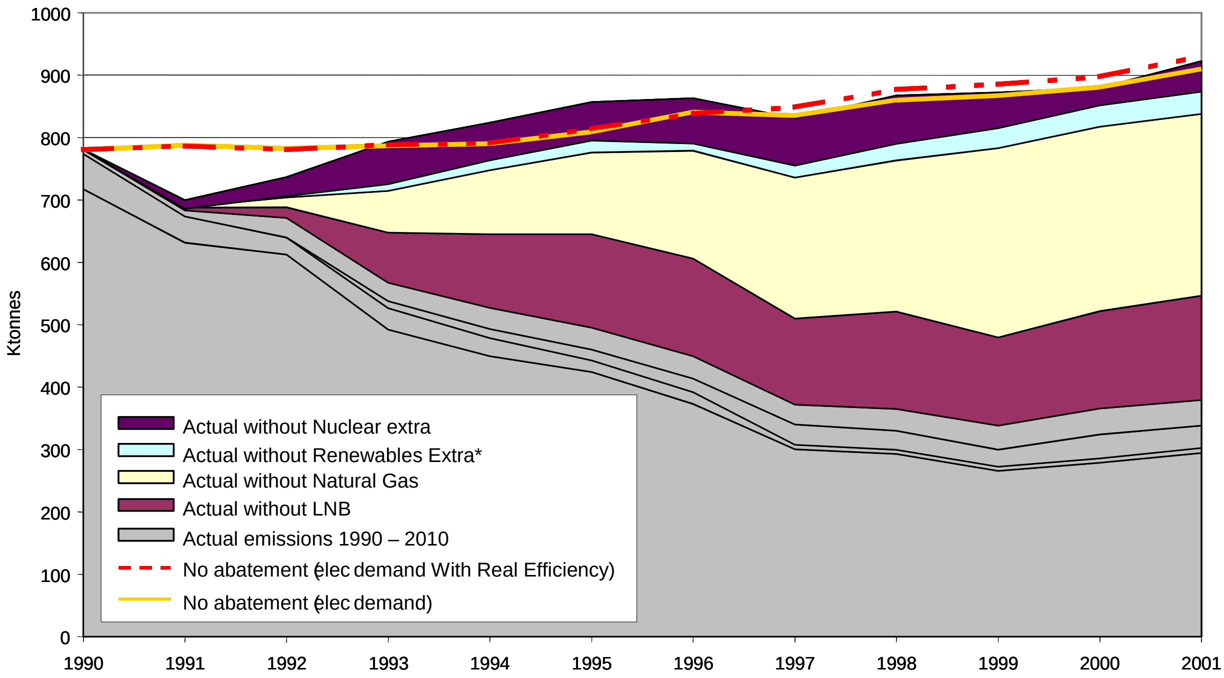


Figure 3-6. Top. Breakdown of SO_2 Emissions Reductions by Technical Option. Bottom. SO_2 emission out-turn from removing individual measures one at a time within the Evaluation Period (1990 – 2001).

3.3.5. The reductions in emission of NO_X are also large. The figures for NO_X are shown below using the same approach (looking at all measures together and removing individual measures one at a time). They show the largest NO_X reductions from natural gas use and low

NO_X burners (coal plant) – there are also smaller reductions from the introduction of renewables and nuclear generation.



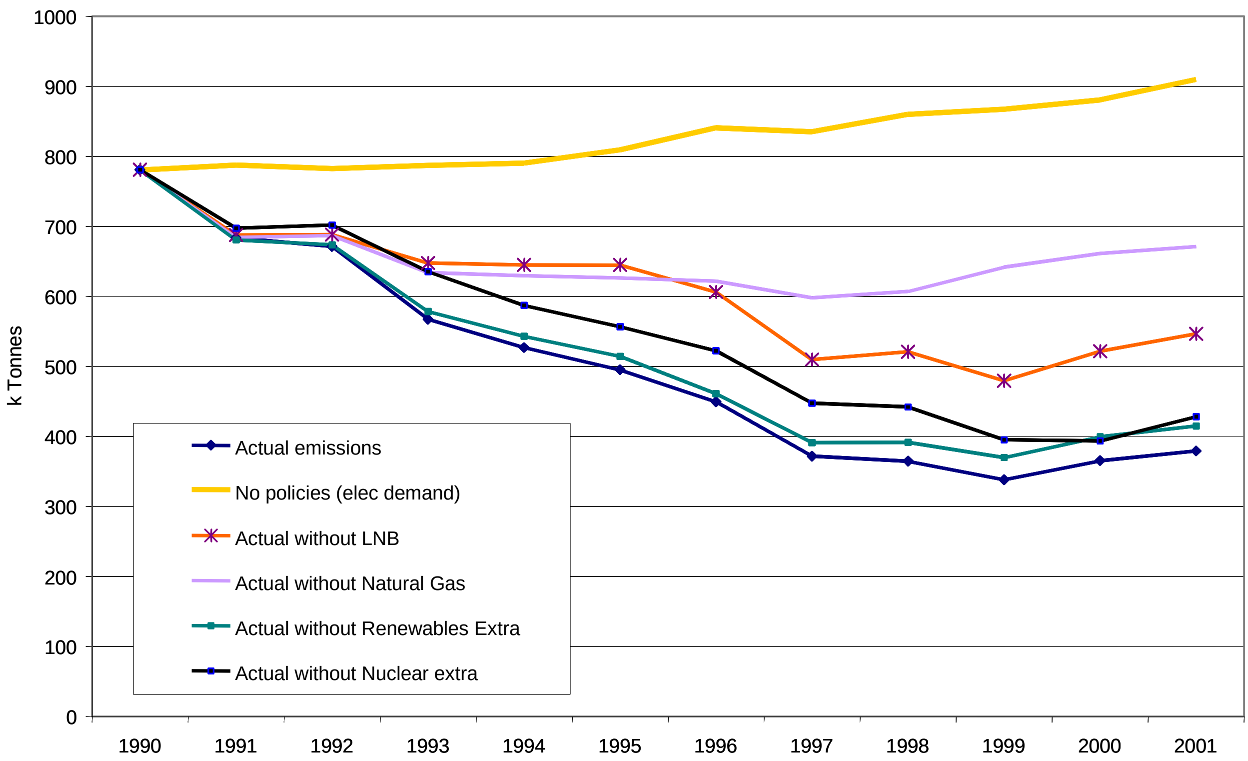
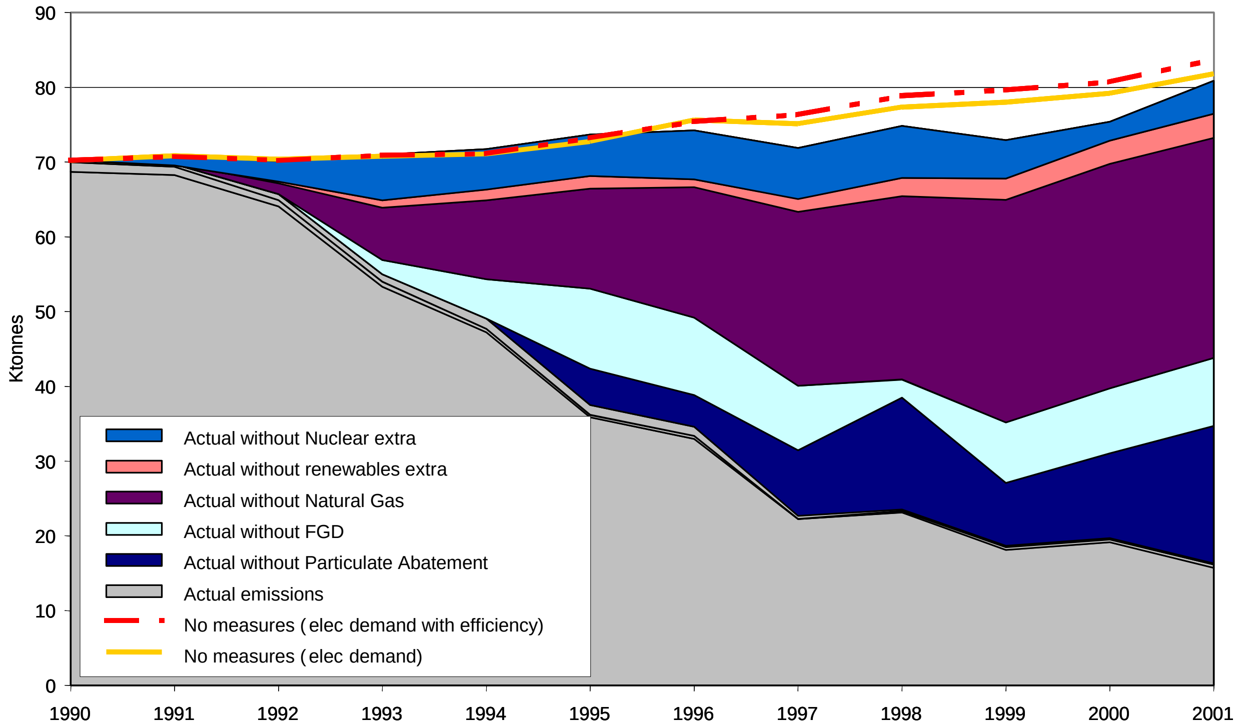


Figure 3-7. Top. Breakdown of NO_X Emissions Reductions by Technical Option. Bottom. NO_X emission out-turn from removing individual measures one at a time within the Evaluation Period (1990 – 2001).

3.3.6. Finally, the analysis has looked at the emissions reductions of PM_{10} by measure. The reductions in emissions of PM_{10} are large, shown below, with gas use and (to a lesser extent) particulate control on coal plant and FGD, having the major effect in reducing emissions.



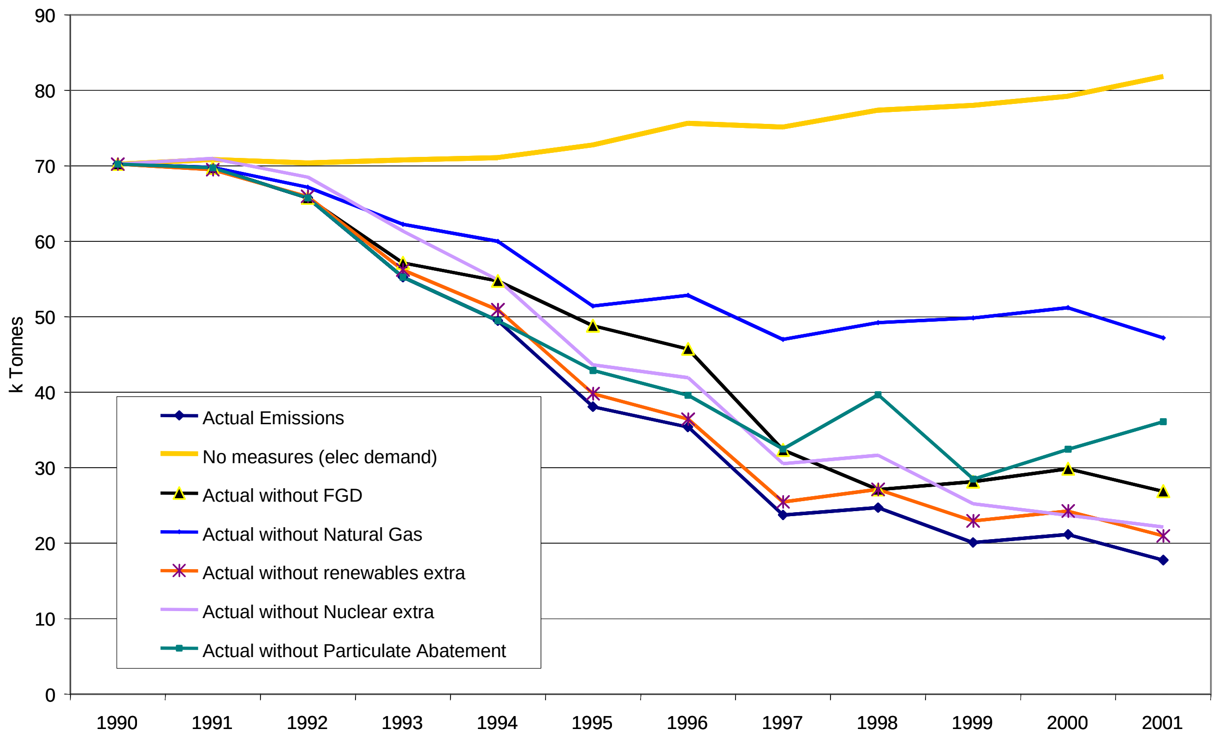


Figure 3-8. Top. Breakdown of PM_{10} Emissions Reductions by Technical Option. Bottom. PM_{10} emission out-turn from removing individual measures one at a time within the Evaluation Period (1990 – 2001).

3.3.7. The emissions reductions of individual measures are summarised in the Table below. Note a number of measures (notably gas use) remain difficult to allocate, because a combination of policies are involved.

Table 3-4. Emissions Reductions of Different Policies in the Evaluation Period (1990 – 2001), relative to the 'no policies' scenario.

SO_2 Emissions Reduction (kt) relative to no abatement (% of reductions by measure)	**Measure**	**Assigned Policy**
1141 (53%)	Gas use	Combination of policies
273 (13%)	FGD for coal stations	*UK Sulphur/IPC**
125 (6%)	Renewables	NFFO
76 (4%)	Oil station closure	Combination
526 (24%)	Lower sulphur content coal.	Integrated Pollution Control
20 (1%)	Lower sulphur content oil.	Liquid Fuels Directive
NO_X Emissions Reduction (kt) relative to no abatement (% of reductions by measure)	**Technical Measure**	**Assigned Policy**
292 (59%)	Gas use	Combination of policies
36 (7%)	Renewables	NFFO
167 (34%))	Low NO_X burners	Integrated Pollution Control
PM_{10} Emissions Reduction (kt) relative to no abatement (% of reductions by measure)	**Technical Measure**	**Assigned Policy**
29.4 (49%)	Gas use	Combination of policies
9.1 (15%)	FGD	*UK Sulphur/IPC**
3.2 (5%)	Renewables	NFFO
18.3 (31%)	PM_{10} abatement for coal/oil	Integrated Pollution Control

* given the UNECE protocol was achieved through gas use anyway, and given that FGD represents an additional cost for generation, additional pressure for operators to fit FGD has been allocated to national policy (IPC and the UK sulphur strategy).

3.3.8. Using the information in the table, and excluding efficiency effects, we estimate the following ranges in attributing emissions reductions to air pollution policy:

- 38 to 100 % of the SO_2 emissions reductions seen can be attributed to air pollution policy.
- 34 to 100% of the NO_X emissions reductions seen can be attributed to air pollution policy.
- 46 to 100% of the PM_{10} emissions reductions seen can be attributed to air pollution policy.

3.3.9. The analysis has also looked at the specific impact of the UNECE policy. The difference between the UNECE target and the actual out-turn is shown below[54]. It shows that emission reductions achieved for SO_2 went beyond that required by the protocol. Note the UNECE target mandated a 50% reduction over 1990 levels by 2000 and this is consistent with around 70% of the SO_2 emissions reductions between the 'without policies' scenario, and the actual policy out-turn. In interpreting the benefits of UNECE policy, it is important to note that the UNECE provided a policy target. However, it was the introduction of gas and IPC that allowed the target to be achieved, i.e. specific policies were required to move towards the

[54] Based on 1980 SO_2 emissions of 3 million tonnes, and associated 30% reduction by 1993, 50% by 2000, 70% by 2005 and 80% by 2010.

target. Of course, in the absence of liberalisation, the UK might still have signed up to the UNECE protocol, and therefore some other combination of measures (e.g. FGD on existing coal stations, higher renewable implementation, additional nuclear build) would presumably have been introduced to meet the target. For the analysis here, we assume that the protocol would have acted as a constraint on emissions for the UK ESI – the actual out-turn, with gas delivering most of the emissions reductions (and IPC the rest) was merely the least cost-way of achieving the policy objective in a liberalised market.

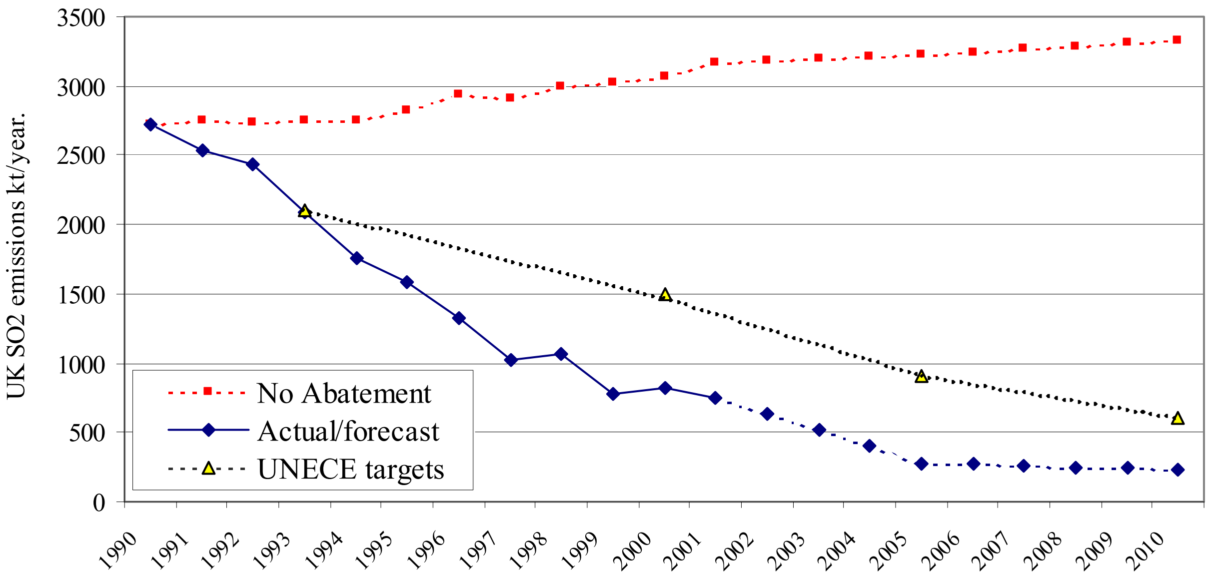


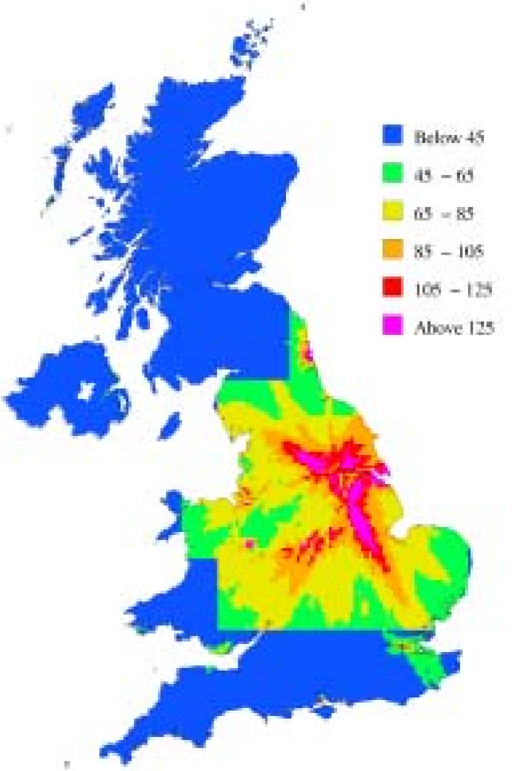
Figure 3-9. Comparison of UK SO_2 emissions: actual emissions, emissions under the no abatement scenario, and the UNECE emission targets.

3.3.10. The policies above have also led to reductions in CO_2. These reductions have occurred alongside the improvements in air quality, though air quality policies are not directly responsible for them.

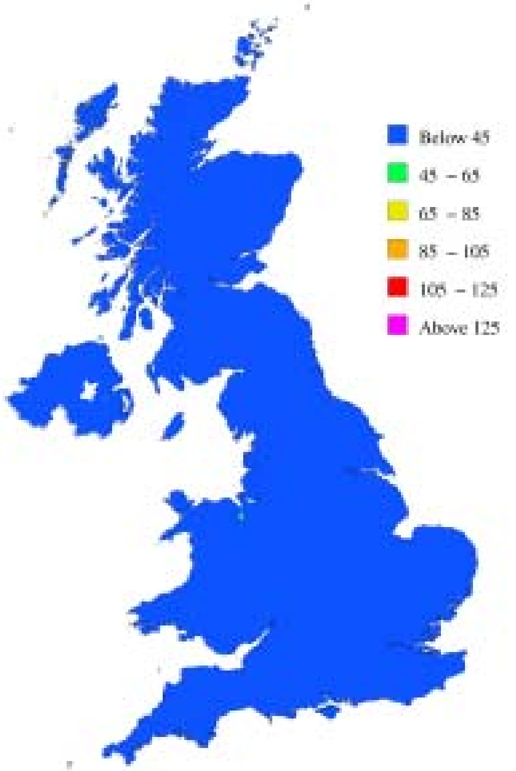
3.3.11. The legislation has also led to benefits in progress toward the UK and EU air quality targets (objectives/limit values), for SO_2, PM_{10} and NO_2 in 2005 and 2010. The objectives for PM_{10} and NO_X were discussed in the previous chapter. For SO_2, there are three relevant objectives from the AQS:

- 125µg/m^3 (47ppb) 24 hour mean 31 December 2004 not to be exceeded more than 3 times a year.
- 350µg/m^3 (132ppb) 1 hour mean 31 December 2004 not to be exceeded more than 24 times a year.
- 266µg/m^3 (100ppb) 15 minute mean 31 December 2005 not to be exceeded more than 35 times a year.

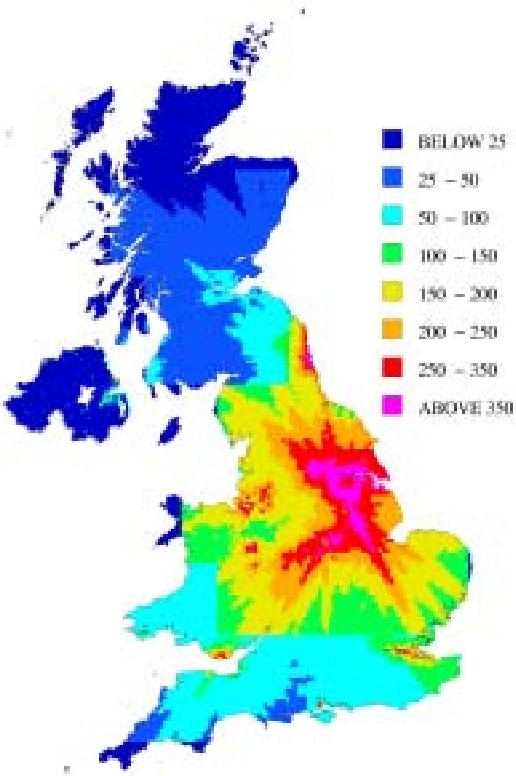
3.3.12. As expected, the ESI policies have made a large difference to ambient SO_2 concentrations and towards meeting the SO_2 objectives. The maps below show the concentrations at background across the UK, with the 'no abatement' scenario on the left and with 'all policies in place' on the right. Note 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.



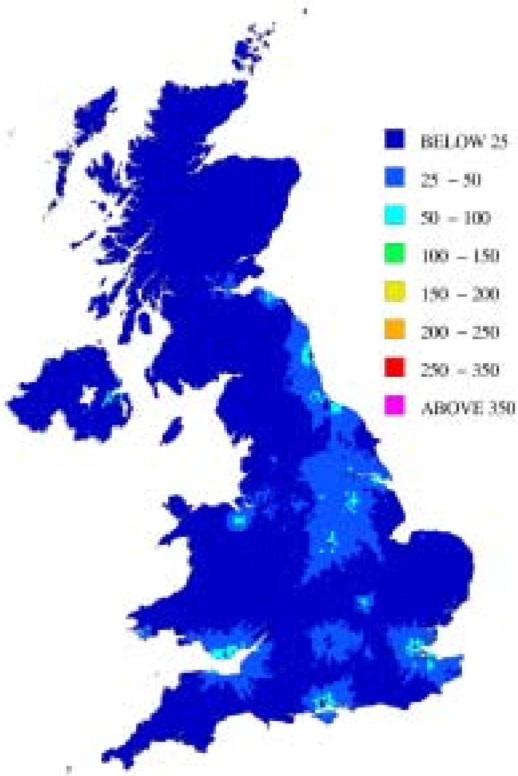
24 Hour Mean SO_2 'No Abatement in the ESI' (2005), μgm^{-3}



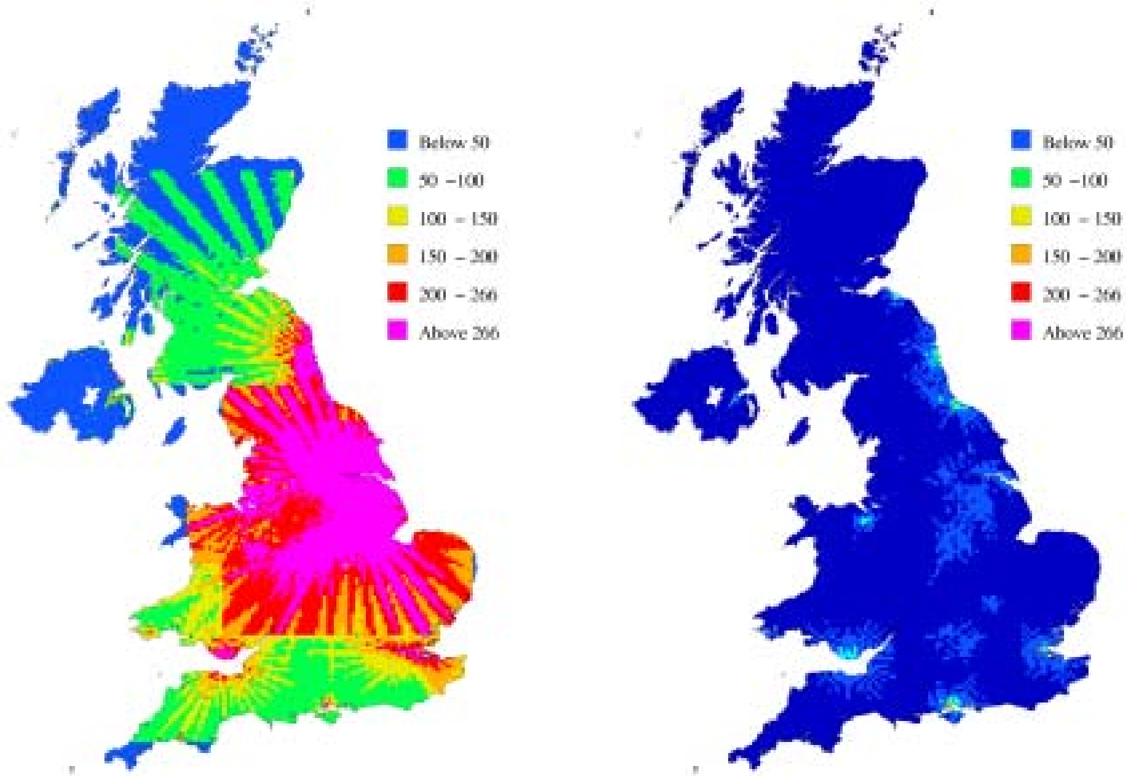
24 Hour Mean SO_2 'All ESI Policies Abatement' (2005), μgm^{-3}



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



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



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

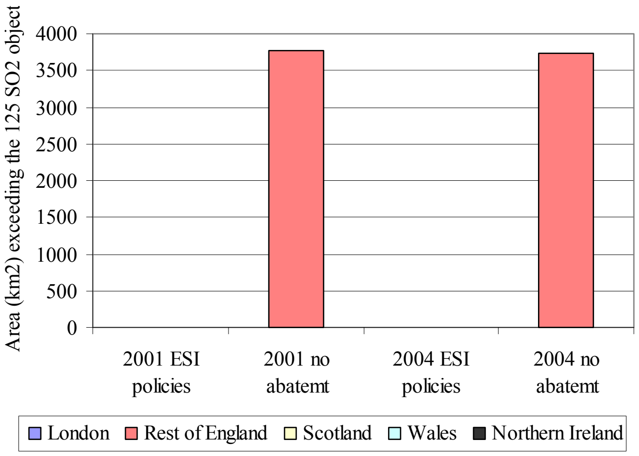
15 Minute Mean SO_2 'All ESI Policies Abatement' (2005), µgm^{-3}

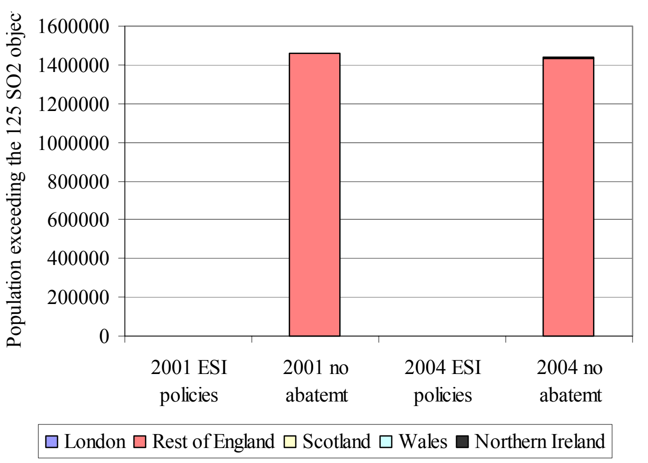
Figure 3-10. SO_2 concentrations under No Abatement and with all ESI Policies in 2005.

3.3.13. Overall, the analysis shows that the policies implemented have been extremely successful in delivering the SO_2 objectives. The annual benefit, in terms of the reduction in the population exposed to exceedences of the objectives, is shown below relative to the no abatement scenario. The exceedences are shown in the figure below – note there were no predicted exceedences in 2001, hence values are only shown for the 'no abatement' scenario.

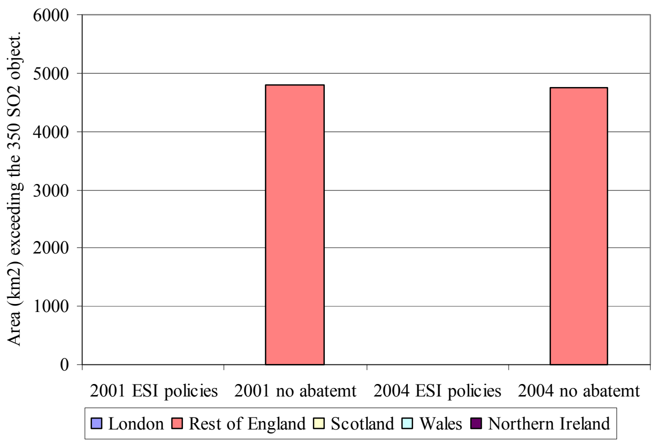
Table 3-5. Annual benefit (as the reduction in the population exceeding SO_2 objectives), from all policies implemented in the ESI, relative to the 'no abatement' scenario

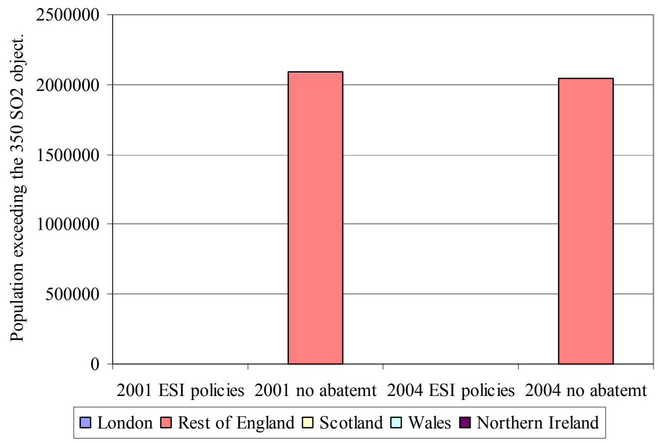
		people per year	
	125 ugm^{-3} as 99.18%ile of daily mean SO_2	350 ugm^{-3} as 99.73%ile of hourly means SO_2	266 ugm^{-3} as 99.9%ile of 15 minute mean SO_2
2001	1,462,163	2,089,264	19,432,837
2004	1,437,996	2,040,886	19,337,231



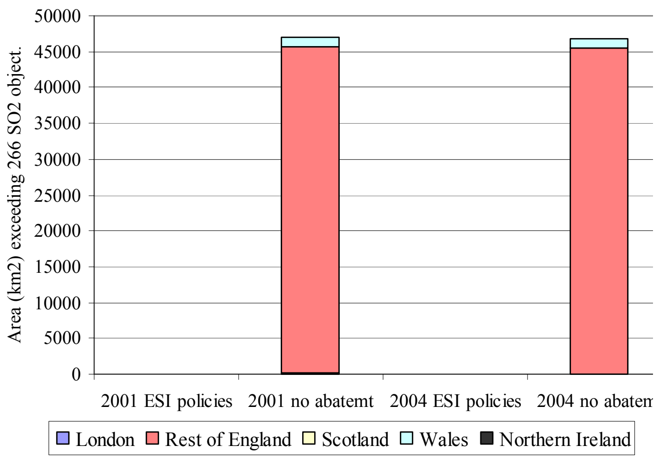


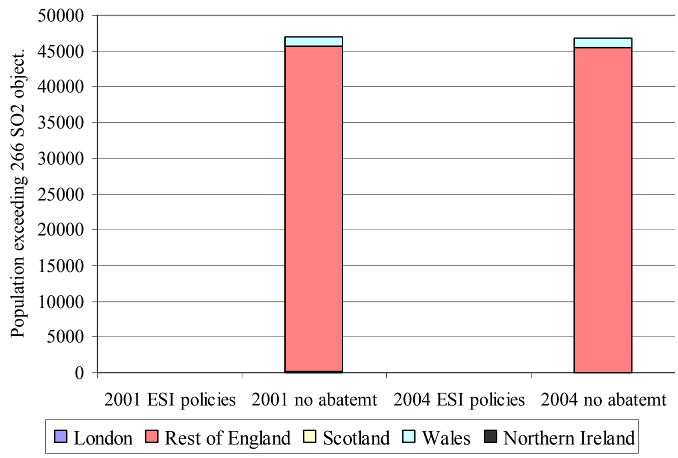
SO_2 125µg/m^3 (47ppb) 24 hour mean





SO_2 350 ugm^{-3} as 99.73%ile of hourly mean





SO_2 266µg/m^3 (100ppb) 15 minute mean

Figure 3-11. Exceedences of SO_2 Objectives for Area (left) and Population (right) with and without policies in the ESI

Note there were no exceedences estimated in 2001, hence the bars only refer to no abatement scenario.

Note the scale of the graphs below is different

3.3.14. The pattern for NO_2 and PM_{10} and the progress against the objectives is shown below for 2005 and 2010. The maps below 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. 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. The pattern is very different to that found for SO_2. For NO_2, there is only a small difference between the 'no abatement' and 'all policy' scenarios. This reflects the relatively small emissions reductions from ESI policies when compared to all sources, and the nature of the emission releases: most of the NO_2 concentrations and exceedence of the objective are the result of transport emissions at roadside or in urban areas. For PM_{10}, the difference between the 'no abatement' and 'all policy' scenarios is greater, though this is not due to primary PM_{10} reductions, but instead the secondary PM_{10} formed from SO_2 emissions (as sulphate) in the 'no abatement' scenario. This shows that the measures implemented in the ESI have led to significant benefits for the PM_{10} concentrations, even though this was not the primary policy aim (the primary aim being SO_2 reductions).

3.3.15. The exceedence data for the key NO_2 objective/limit value ($40\mu g/m^3$ annual mean) in the UK are summarised below. This shows the exceedences for the predicted out-turn with all policies in place (the baseline = with all policies in place), and the 'no abatement' out-turn (no policies in place) for the years 2001, 2005 and 2010. Exceedences have been measured in terms of the area and population exposed to $> 40\mu g/m^3$ at background locations. The analysis shows that the expected out-turn (with policies in place) only lead to a small benefit in the reduction in exceedences of NO_2 compare to the 'no abatement' scneario. There are some minor benefits in earlier years, with a reduction of 177,000 people exposed to concentrations above the objective ($40\mu g/m^3$ NO_2) in 2001 relative to the no abatement and 9,700 people in 2005, but no difference in the population exposed in 2010 between the 'no abatement' and 'all policies'.

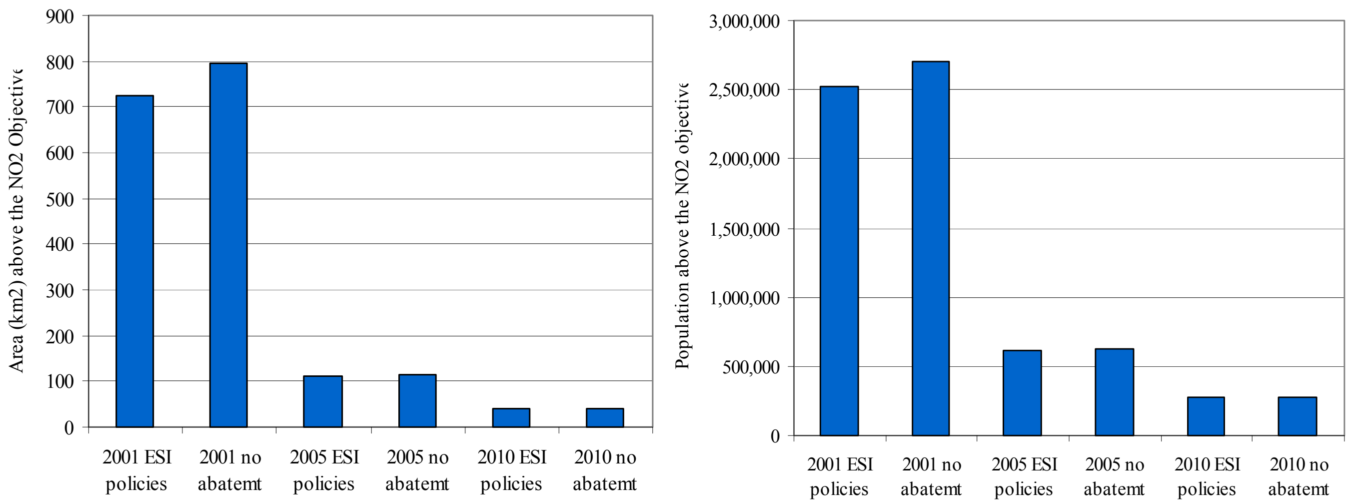
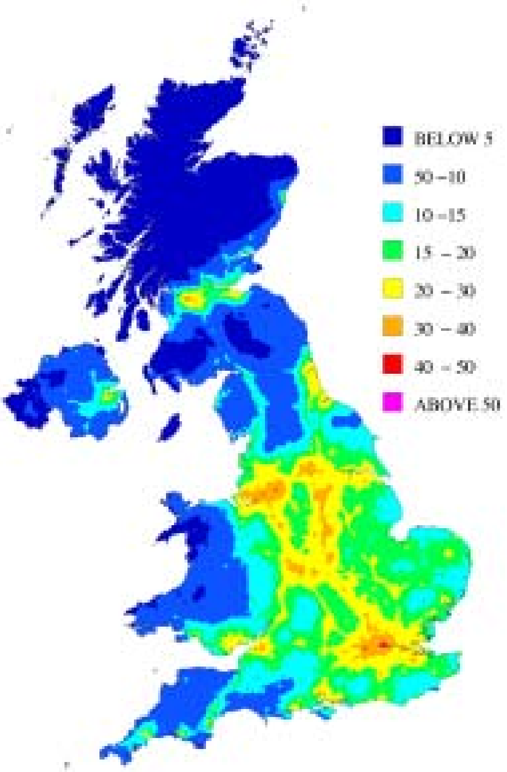
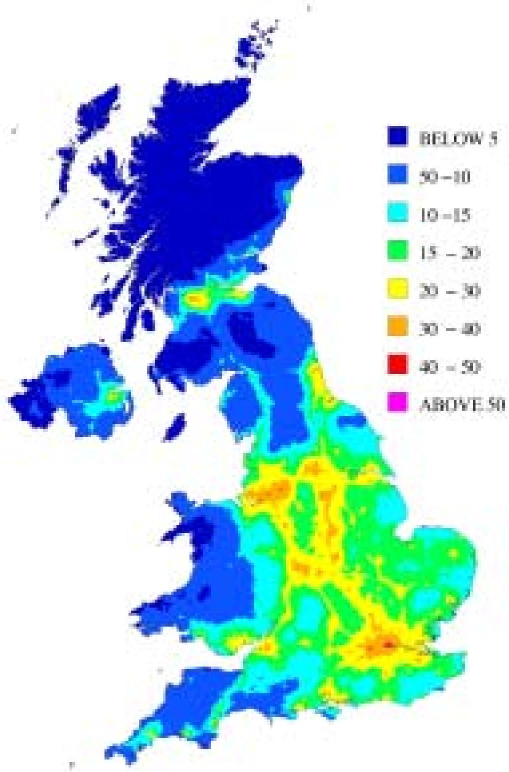


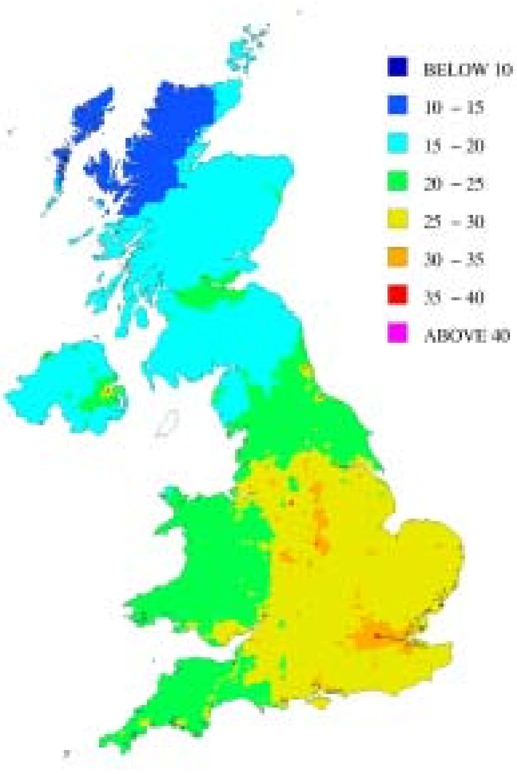
Figure 3-12. Exceedences of NO_2 Annual Mean for Area (left) and Population (right) with and without policies in the Electricity Generation sector.



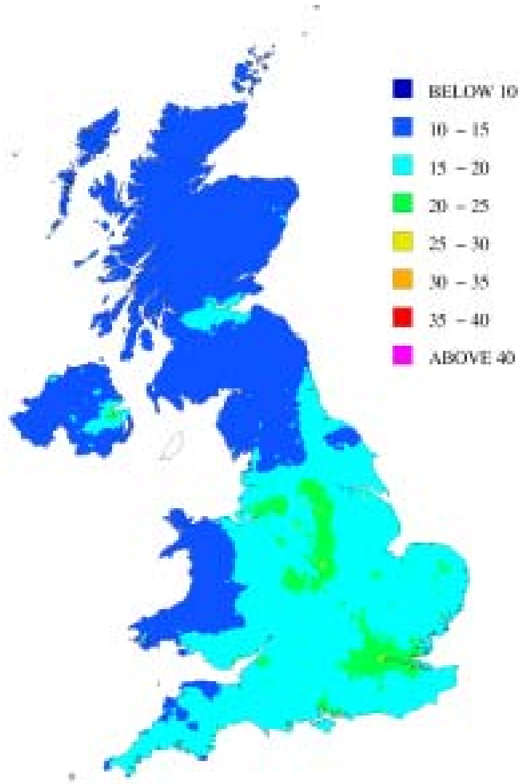
Annual Mean Background NO_2 'No Abatement in the ESI' (2005), μgm^{-3}



Annual Mean Background NO_2 All Policies (2005), μgm^{-3}

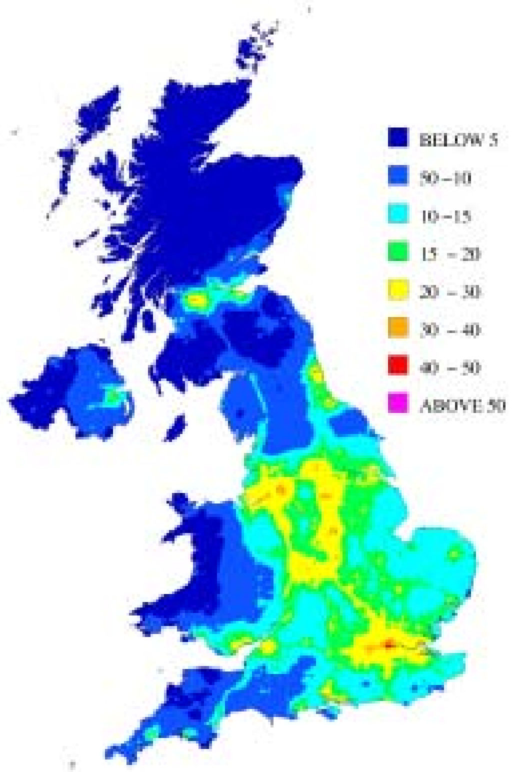


Annual Mean Background PM_{10} 'No ESI' Abatement (2005), μgm^{-3} (gravimetric)

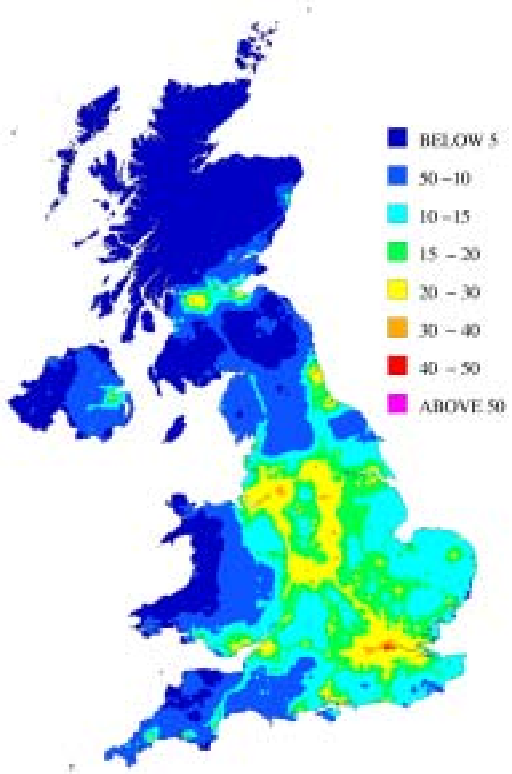


Annual Mean Background PM_{10} All Policies (2005), μgm^{-3} (gravimetric)

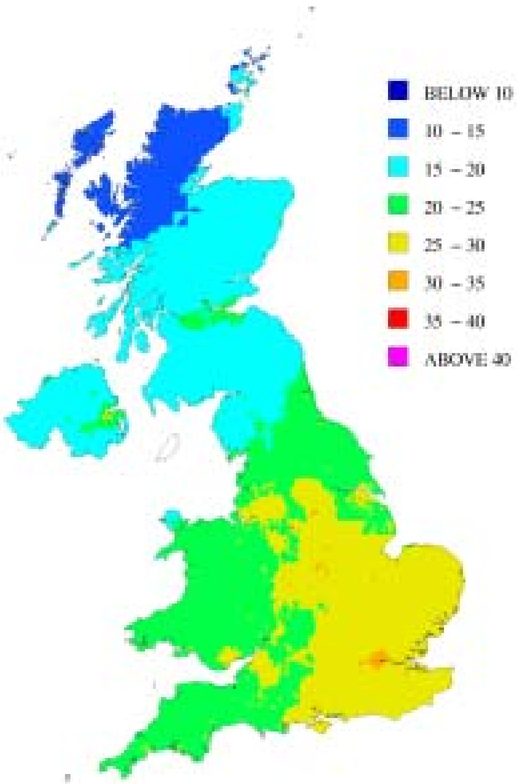
Figure 3-13. NO_2 and PM_{10} under the No Abatement and with all ESI Policies in 2005.



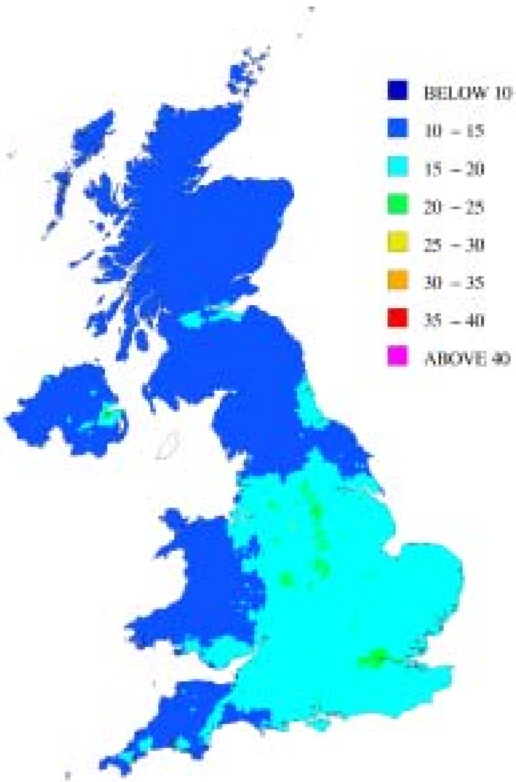
Annual Mean Background NO_2 'No Abatement in the ESI' (2010), µgm^{-3}



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



Annual Mean Background PM_{10} 'No ESI' Abatement (2010), µgm^{-3} (gravimetric)



Annual Mean Background PM_{10} All Policies (2010), µgm^{-3} (gravimetric)

Figure 3-14. NO_2 and PM_{10} under the No Abatement and with all ESI Policies in 2010.

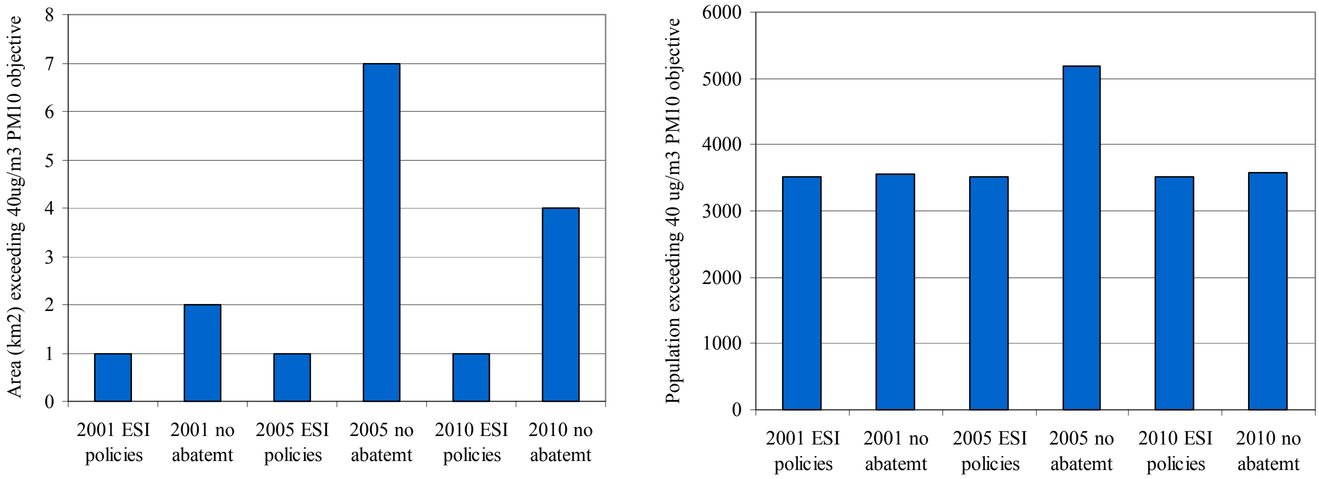
3.3.16. Given most exceedences are at road-side in future years, targeting further NO_X emission reductions from the ESI is not a useful or cost-effective way of progressing towards the NO_2 objective. However, as later sections will discuss, there are still benefits in reducing NO_X from the ESI, because it will reduce the formation of secondary pollutants (ozone and nitrates).

3.3.17. A different pattern is found for PM_{10} shown below. The data is shown for the 'no abatement' and with 'all policies' for the three objectives: annual mean 40µg/m^3, 50µg/m^3 24 hour mean not to be exceeded more than 35 times a year (equivalent to an annual mean 31.5µg/m^3) and annual mean 20µg/m^3. For the 40µg/m^3 objective, there is almost no difference between the two scenarios. This would be expected given the tall stack emissions from the ESI would not make as important a contribution to PM_{10} concentrations as transport emissions in the urban areas where population exposure is greatest. However, a different pattern does start to emerge with lower objective levels. This is shown in the 20 µg/m^3 objective, where the difference between the 'no abatement' and 'with policies' is very significant. This is due to the importance of SO_2 in secondary particulate formation – due to the high SO_2 emissions in the no abatement scenario and the low objective level, the secondary PM_{10} formed is significant enough to dramatically increase the population exposed to levels above the threshold. Therefore the ESI policies have had a major impact in reducing PM_{10} exposure (at least at low objective levels). This also raises important issues for future policy (discussed later). Reducing SO_2 further may actually have a large impact on reducing the remaining background concentrations of PM_{10} (because of the reduction of sulphates). The annual benefit, in terms the population exceeding the objectives is shown below.

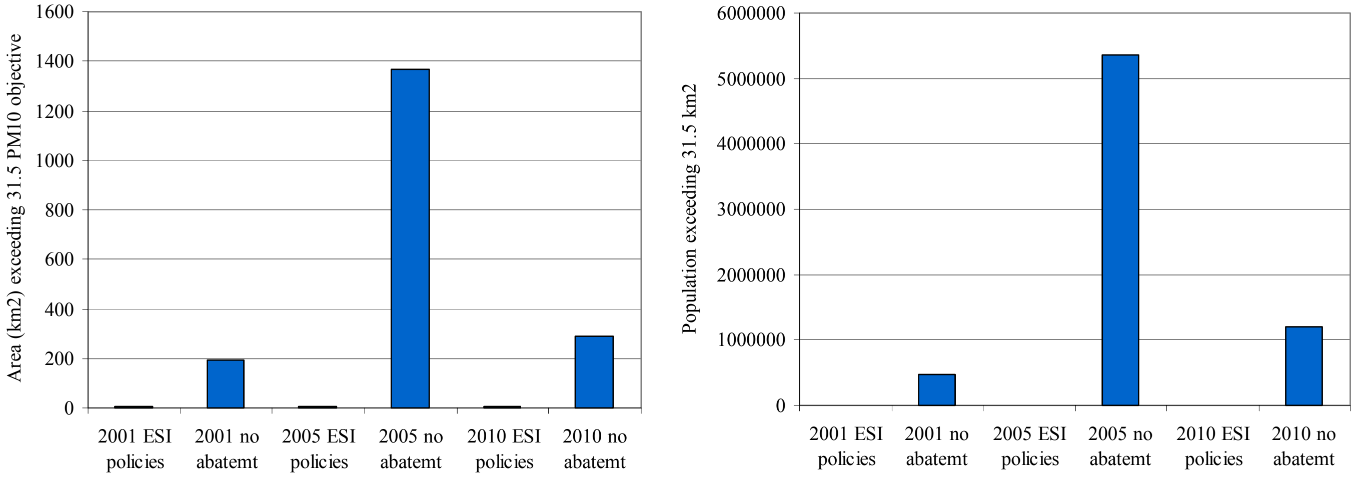
Table 3-6. Annual benefit (as reduction in the population exceeding the PM_{10} objective), from all policies implemented in the ESI, relative to the 'no abatement' scenario

		people per year	
	40 ugm^{-3} gravimetric annual mean)	31.5 ugm^{-3} gravimetric annual mean	20 ugm^{-3} gravimetric annual mean
2001	36	465,444	20,489,007
2004	1670	5,347,305	29,784,118
2010	69	1,189,868	43,691,926

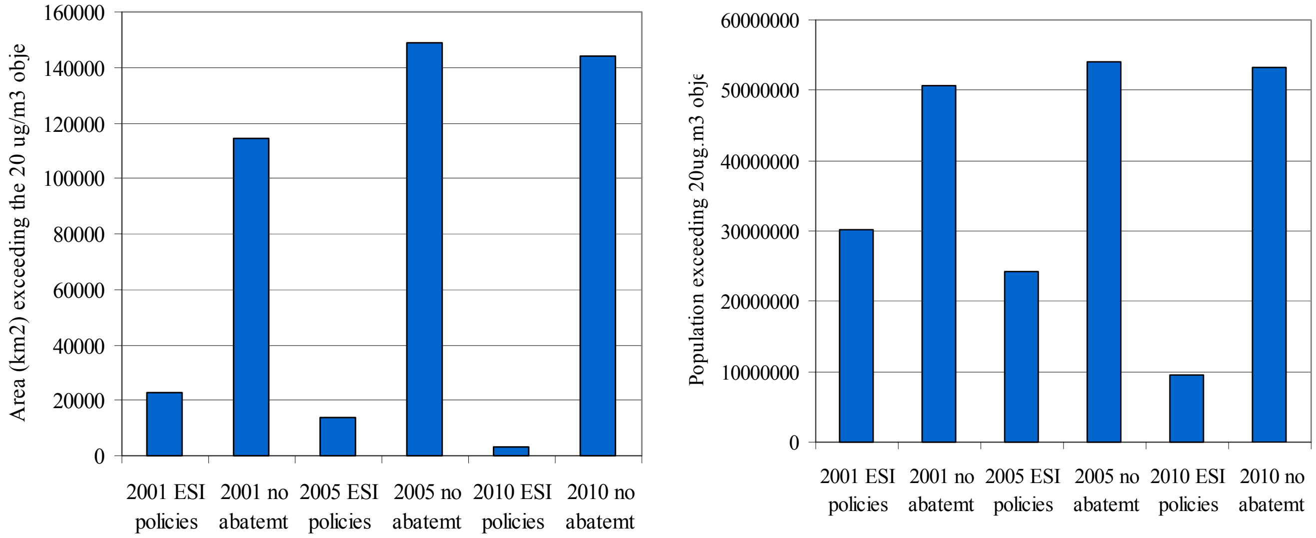
3.3.18. Overall, the analysis also shows there have been major benefits from policies in the ESI in reducing the potential health effects of SO_2 (from meeting the objectives for SO_2) and in the contribution to reducing PM_{10} concentrations (from reducing secondary particulates). The secondary effect is probably more important, because the current lack of evidence for a threshold for PM_{10} would mean that health impacts will occur below the objective (though it assumes that sulphates have the same health impact causality as primary PM_{10}). This might indicate that national level policies would still be very beneficial with respect to secondary PM_{10} (from SO_2) and its health effects. The benefits of SO_2 (gaseous) reductions are more contentious – as the role of gaseous SO_2 in health impacts remains unclear: whilst COMEAP has accepted causality for gaseous SO_2, other organisations have been more cautious in quantification.



PM_{10} Annual Mean 40µg/m^3 (gravimetric)



PM_{10} 24 Hour Mean (Equivalent Annual Mean 31.5µg/m^3) (gravimetric)



PM_{10} Annual Mean 20µg/m^3 (gravimetric)

Figure 3-15. Exceedences of PM_{10} Objectives for Area (left) and Population (right) with and without policies in the ESI (including primary and secondary PM_{10}).

Note the scale of the graphs below is different

3.4 Health and Economic Benefits of the Policies

3.4.1. The benefits from reductions in air pollution were set out in the previous chapter (see Boxes 2.1, 2.2 and 2.3, and text in section 2.4). This section applies the same approach to estimate the health and economic benefits for the ESI. The air quality improvements, as shown in the pollution maps above, have significantly reduced the population exposed to air pollution, and therefore the potential health impacts of air pollution in the UK. The analysis has quantified how much improvements in the ESI are estimated to have already reduced the main health impacts of concern (to 2001), compared to the 'no abatement' scenario, and how much they are projected to do so in the future (to 2010). We stress that the analysis here first looks at the total air quality benefits from all environment and energy policies from action in the ESI. It then goes on to look at the allocation of benefits to specific air quality policies, to split out the effects that can be attributed to air quality policy, and wider energy policies.

3.4.2. Figure 3-16 shows the estimated health effects in the UK (only) for PM_{10} reductions (the main pollutants of concern) in terms of deaths brought forward (left), with and without the ESI policies. The difference between the two lines on the left hand graph is the benefit achieved from policies, i.e. from reductions in total PM_{10} (both primary and secondary PM_{10}). 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 power stations, but also the reduction in secondary particulates from NO_X and SO_2 emissions. The analysis shows that ESI policies have already (2001) led to am annual reduction of around 1522 in the number of people per year whose life is shortened by pollution in days before death. This is projected to increase to a benefit of 2836 people per year by 2010. This is a much larger value than for the transport sector. These benefits have been attributed to the different components of the PM_{10} pollution mix on the right hand side of the figure. This shows that these health benefits are dominated by the reduction in sulphates (secondary PM_{10}).

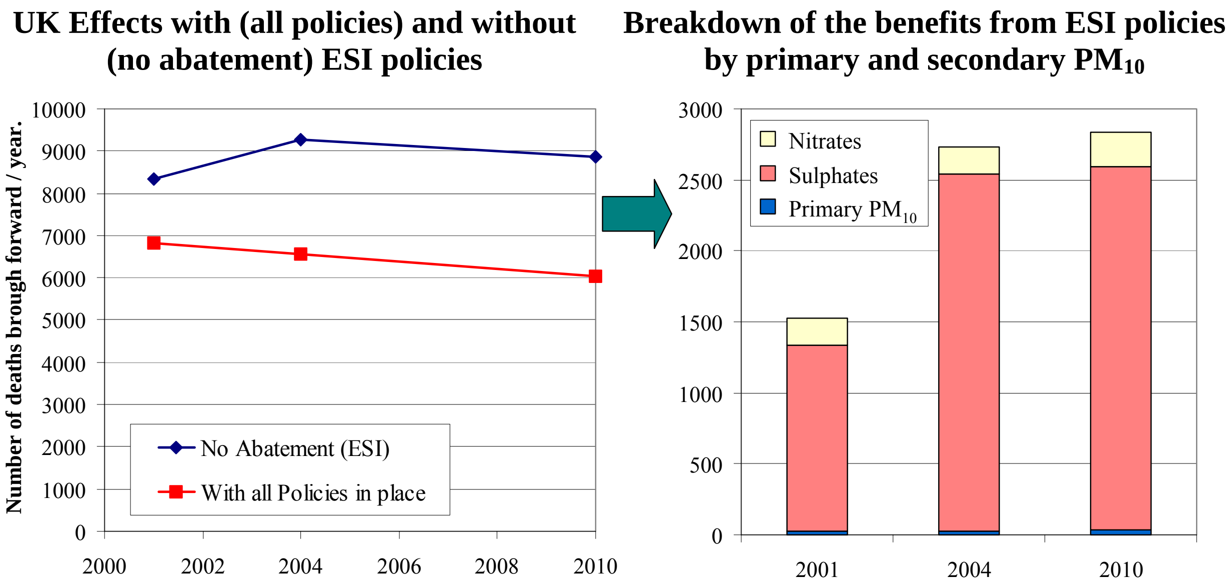


Figure 3-16. Estimated Annual Deaths Brought Forward in the UK from PM_{10} (Data for 2001 Actual. Data for 2004 and 2010 Projected.)

Note that the figure on the left shows the differences between the projected out-turn for the whole UK and the 'no abatement' scenario where no ESI policies are introduced (but improvements in other sectors do occur). The figure shows the benefit from the pollution change in the individual year (2001,2005 and 2010) compared with the predicted out-turns 'without' policy for that year.

3.4.3. The analysis has also assessed the long-term benefits from ESI policies for PM_{10}. Figure 3-17 shows the estimated health effects in the UK (only) in terms of the change in life expectancy (left), with and without ESI policies. Note a central low and a central high value are presented. The difference between the two lines on each of the two left hand graphs is the benefit achieved from ESI policies. It is stressed that the benefits include the reduction of primary PM_{10} from power stations, but also the reduction in secondary particulates from emissions of NO_X and SO_2. Again, the values for 2001 are based on the actual data (ex post), whilst the values for 2005 and 2010 are projected. The analysis shows that ESI policies have already (2001) led to large reduction in the years of life lost. This is projected to increase significantly by 2010. These benefits have been attributed to the different components of the PM_{10} pollution mix on the right hand graph (which obviously follows the pattern for short-term effects above). This shows that these health benefits are dominated by the reduction in secondary PM_{10} from sulphates. Note that life expectancy benefits from reduced long-term exposure to PM are now well accepted, though questions remain about how quickly the benefits follow on from pollution reduction; these benefits would have been considered controversial, or unquantifiable, at the time when earlier policies were being decided (*ex ante* benefits in policy appraisal).

3.4.4. The benefits of short-term and long-term benefits from air pollution reductions are summarised in the table below. The analysis shows that the annual benefits achieved by the end of the evaluation period in 2001 are high. This is different to the results of transport policies, which showed a much lower proportion of benefits in the evaluation period. This reflects the earlier move towards lower sulphur emissions in the evaluation period for the ESI. The total health benefits are also much greater than for the transport sector.

Table 3-7. Annual PM_{10} Health Benefits in the UK from All ESI Policies: Achieved (2001) and Projected to Occur (2010), relative to the No Abatement Scenario

Health Effect	Actual annual benefit in 2001	Projected annual benefit in 2010
Deaths brought forward	1,522	2,836
Respiratory hospital admissions	1,491	2,779
Life years saved	29,320 (central low) to 87,961 (central high)	54,641 (central low) to 163,923 (central high)

The table shows the benefit from the pollution change in the individual year (2001 and 2010) compared with the predicted out-turns 'without' policy for that year.

The benefits shown are the difference between the UK out-turn (with ESI policies) and the 'no abatement' scenario (with no ESI policies, but with improvements in other sectors). Values include benefits from both primary and secondary PM_{10}. Note analysis of life years saved is based on exposure to PM experienced for a 1-year pollution increment assuming no lag effects. The numbers presented are undiscounted. Only benefits in the UK are included (no trans-boundary benefits). Central low/high only includes variation in risk factor for chronic mortality. Values include primary and secondary PM_{10}.

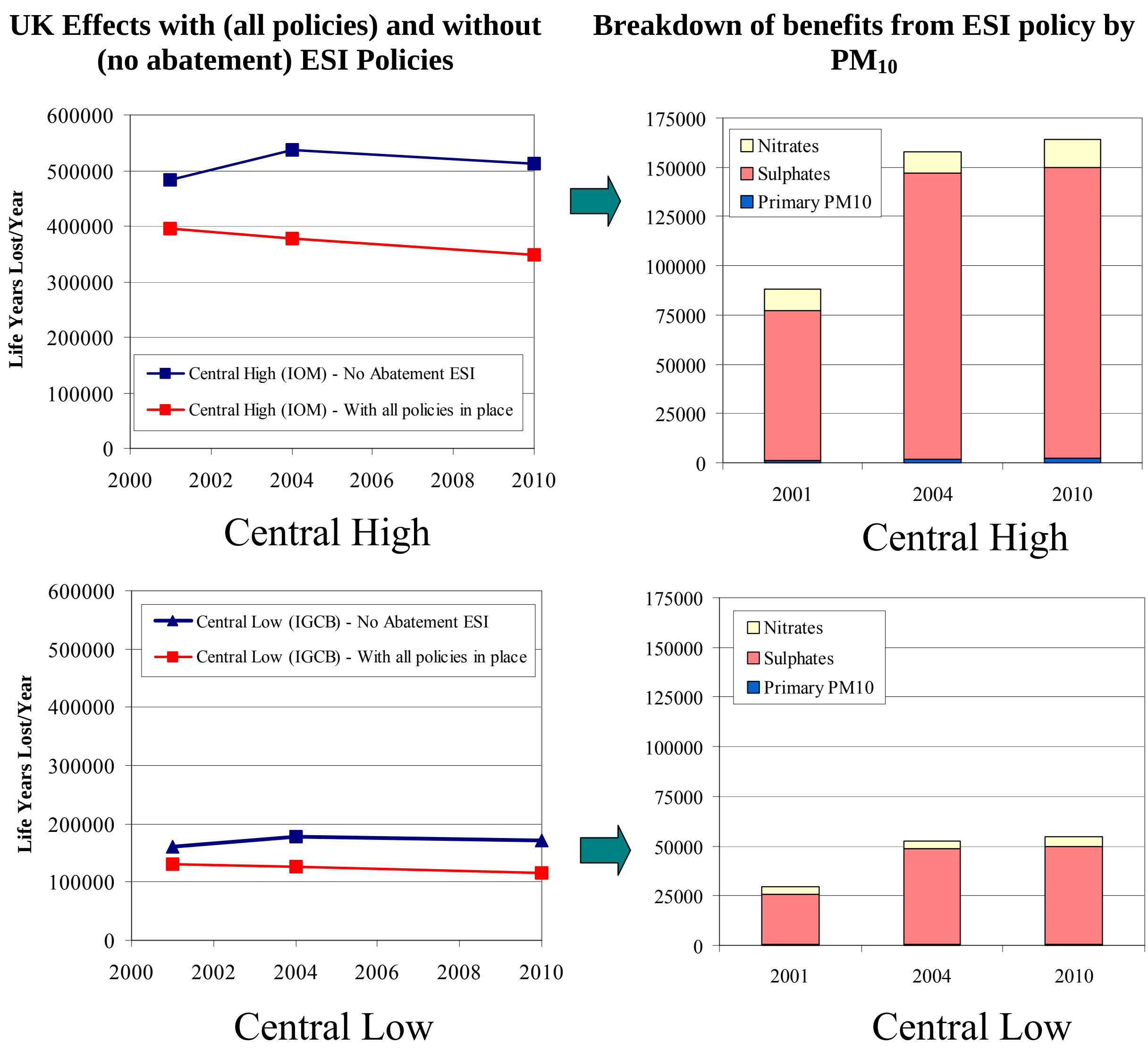


Figure 3-17. Number of Annual Life Years Lost in the UK from PM_{10} concentrations (Data for 2001 Actual. Data for 2004 and 2010 Projected.)

The figure shows the benefit from the pollution change in the individual year (2001,2005 and 2010) compared with the predicted out-turns 'without' policy for that year. Note that the figure on the left shows the differences between the projected out-turn for the whole UK and the 'no abatement' scenario where no ESI policies are introduced (but improvements in other sectors do occur). The analysis of life years saved is based on exposure to PM_{10} experienced for a 1 year pollution increment, assuming no lag effects. It is based on the life-table approach, following up the population exposed to the 1-year pollution change until all have died. 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. The analysis accounts for the potential differences between PM_{10} measurement techniques (TEOM vs. gravimetric). For more details on methodology see Chapter 2.

3.4.5. The economic benefits of these health improvements is shown in the table below. They show the ESI policies in place have had very large economic benefits within the evaluation period (by 2001). For example, the total benefits from policies, from the reduction in all PM_{10} (primary and secondary), are estimated to be £758 Million to £4841 Million/year (central low to central high), relative to the no abatement scenario. These are the ex post benefits achieved to date (2001). By 2010, these benefits are projected to increase to £1413

Million to £8791 Million/year (CL – CH) relative to the no abatement scenario. It is stressed that the life years saved, even when discounted, dominate these benefits. The inclusion of other pollutants (see later analysis) would increase these benefits further.

Table 3-8. Annual PM_{10} Related Economic Benefits in the UK from ESI Policies: Achieved (2001) and Projected to Occur (2010), relative to the No Abatement Scenario

Health Effect	Actual annual benefit (2001) £ Million	Projected annual benefit (2010) £ Million
Deaths brought forward	4.7 (central low) to 167 (central high)	8.8 (central low) to 312 (central high)
Respiratory hospital admissions	3.9	7.3
Life years saved (discounted @ 1.5%)	750 (central low) to 4643 (central high)	1397 (central low) to 8652 (central high)
TOTAL	**758 (central low) to 4814 (central high)**	**1413 (central low) to 8791 (central high)**

For caveats, see Table 3-7. Note the valuation of future life years saved from annual pollution in 2001 and annual pollution in 2010 have both been discounted (using a rate of 1.5%). 2010 values assume constant prices. The central low and central high values include a variation in the risk factor for chronic mortality, and a range in the valuation of deaths brought forward and chronic mortality.

3.4.6. Note the values above **only include the benefits of air quality improvements in the UK, from the implementation of policies in the UK**. We stress that this is the most relevant metric for the evaluation (and was specified in the study terms of reference). However, it does raise a number of issues (also raised in the transport chapter).

- Firstly, the benefits presented here are a sub-total of the full social benefits of UK emission reductions (and UK policies), because they do not include additional health benefits in the rest of Europe.
- Secondly, the evaluation does not include the benefits to the UK from implementation of policies or agreements in the rest of Europe in the UK. This is particularly important for the earlier international negotiations of SO_2.

3.4.7. The health impacts and economic benefits of all ESI policies, for all pollutants, are presented in the following tables. They include the benefits of all policies, relative to the 'no abatement' scenario (irrespective of whether these are due to environmental policy, or wider energy policy). The analysis is split by pollutant, and classified using the confidence bands outlined in the previous chapter.

- Table 3-9 presents the annual health benefits from ESI policies in the UK for the evaluation date (2001) and projected to occur with existing policies (by 2010). This is based on the detailed mapping analysis for the years 2001 and 2010.
- Table 3-10 presents the annual economic benefits from the above analysis, in 2001 and 2010, including health and non-health benefits.
- Table 3-11 presents the total benefits from ESI policies in the evaluation period (to 2001) and projected to occur from 2002 to 2010. These values have been calculated by using the detailed mapping and valuation analysis above to estimate the marginal benefits of air quality improvements (expressed as a cost per tonne). The results have been used to estimate the benefits in all years over the evaluation period and projections.

Table 3-9. Annual UK Health Benefits (Cases) from All ESI Policies. Benefit achieved (2001) and Projected to Occur (2010), relative to the No Abatement Scenario.

Pollutant and Impact	Confidence Ranking	Actual annual benefit as number cases in 2001	Projected annual benefit as umber cases in 2010
Primary PM_{10} on health	High		
Deaths brought forward (DBF)		22	37
Respiratory Hospital Admissions (RHA)		22	37
Chronic Mortality (CM).		429 to 1287 (CL-CH)	718 to 2155 (CL-CH)
SO_2 as a gas on health			
DBF		2203	2351
RHA		1556	1799
VOC and impacts on health (DBF/RHA) through formation of **ozone**		Not quantified	Not quantified
NO_X and impacts on health (DBF/RHA) through formation of **ozone**		Not quantified	Not quantified
SO_2 as secondary PM_{10} (sulphates)	Medium		
Deaths brought forward (DBF)		1315	2556
Respiratory Hospital Admissions (RHA)		1288	2504
Chronic Mortality (CM).		25332 to 75997 (CL-CH)	49250 to 147750 (CL-CH)
NO_X as secondary PM_{10} (nitrates)	Low		
Deaths brought forward (DBF)		185	243
Respiratory Hospital Admissions (RHA)		181	238
Chronic Mortality (CM).		3559 to 10677 (CL-CH)	4672 to 14017 (CL-CH)
Additional PM_{10} health impacts (includes primary and secondary PM_{10})	**Sensitivity analysis (NOT recommended by COMEAP*)**		
Cardiovascular admissions (CA)*		871	1623
A&E visits for respiratory illness (A&E)		2220	4137
GP visits: Asthma		32756	61043
GP visits: Lower respiratory symptoms		15974	29769
Restricted activity days		5208236	9705941
Respiratory symp. in adult asthmatics		1745801	3253431
Respiratory symp. in child asthmatics		652380	1215759
NO_2 as a gas on health*			
Respiratory Hospital Admissions (RHA)		37	46

* Respiratory Hospital Admissions (RHA) for NO_2 and Cardiovascular admissions (CA) for particulates were recommended for sensitivity by COMEAP (1998:2001).

The table shows the benefit from the pollution change in the individual year (2001 and 2010) compared with the predicted out-turns 'without' policy for that year.

See text for caveats. Note the numbers above only include UK benefits, and do not account for the benefits arising outside the UK from the reduction in trans-boundary pollution.

CL = Central Low. CH = Central High. This range only includes variation in the risk factor for chronic mortality.

Table 3-10. Annual Economic Benefits in the UK from All ESI Policies. Benefit achieved (2001) and Projected to Occur (2010), relative to the No Abatement Scenario.

Pollutant and Impact	Confidence Ranking	Actual Annual benefit in 2001 £ Million	Projected Annual benefit in 2010 £ Million
PM_{10} on health Deaths brought forward (DBF) Hospital Admissions (RHA) Chronic Mortality (CM).	**High**	0.1 to 2.5 (CL-CH) 0.1 11.0 to 68.0 (CL-CH)	0.1 to 4.1 (CL-CH) 0.1 18.4 to 114 (CL-CH)
SO_2 as a gas on health DBF and RHA **SO_2 / secondary buildings** (corrosion)		10.5 to 228 (CL-CH) 547	12 to 263 (CL-CH) 696
VOC and impacts on health (ozone) *plus* **VOC and impacts on crops (ozone)**		Not quantified	Not quantified
NO_X and impacts on health (ozone) *plus* **NO_X and impacts on crops (ozone)**		Not quantified	Not quantified
TOTAL	**High**	**569 to 846 (CL-CH**	**727 to 1077 (CL-CH**
SO_2 as secondary PM_{10} (sulphates) Deaths brought forward (DBF), Respiratory Hospital Admissions (RHA) Chronic Mortality (CM).	**Medium**	4.1 to 145 (CL-CH) 3.4 648 to 4011(CL-CH)	7.9 to 281 (CL-CH) 6.6 1259 to 7798(CL-CH)
TOTAL	**Medium**	**655 to 4159 (CL-CH**	**1274 to 8086(CL-CH**
NO_X as secondary PM_{10} (nitrates) Deaths brought forward (DBF) Respiratory Hospital Admissions (RHA) Chronic Mortality (CM).	**Low**	0.6 to 20.3 (CL-CH) 0.5 91 to 564 (CL-CH)	0.8 to 26.7(CL-CH) 0.6 120 to 740 (CL-CH)
TOTAL	**Low**	**92 to 584 (CL-CH**	**121 to 767 (CL-CH**
Greenhouse Gas Emissions (CO_2)** Social cost of carbon	**Low**	665 to 2660	1142 to 4568
TOTAL	**Low GHG**	**665 to 2660**	**1142 to 4568**
Additional PM_{10} morbidity health impacts (includes primary and secondary PM_{10}) Respirator symptoms (CA*/A&E/GP visits) Restricted activity days Respiratory symptoms in asthmatics	**Sensitivity analysis** **(NOT recommended by COMEAP*)**	 4.4 517 319	 8.2 961 594
NO_2 as a gas on health Respiratory Hospital Admissions*		0.1	0.1
TOTAL	**Sensitivity**	**841**	**1563**

See text and previous table for caveats*. Note the numbers only include UK benefits. CL = Central Low. CH = Central High. This range only includes variation in the risk factor for chronic mortality, and the valuation of deaths brought forward and chronic mortality. Note the valuation of future life years saved from annual pollution in 2001 and annual pollution in 2010 have been discounted at 1.5%. 2010 values assume constant prices.

** The values shown relate to the illustrative range for the social cost of carbon from £35/tC to £140/tC. These benefits have occurred alongside the improvements in air quality, though air quality policies are not directly responsible for these benefits.

Table 3-11. Economic Benefits from All ESI Policies. Total benefit achieved (2001) and Projected to Occur (2010), relative to the No Abatement Scenario.

Pollutant and Impact	Confidence Ranking	Evaluation (ex post benefit) 1990 - 2001 £ Million	Projected benefit 2002 - 2010 £ Million
PM_{10} on health (DBF), (RHA) (CM).	High	65 to 412 (CL-CH)	109 to 692 (CL-CH)
SO_2 as a gas on health (DBF/RHA). *plus* **SO_2 / secondary pollutants on building**		3607 to 4886 (CL-CH)	5987 to 8111 (CL-CH)
VOC and impacts on health (DBF/RHA) **VOC and impacts on crops** (yield loss) through formation of **ozone**		Not quantified	Not quantified
NO_X and impacts on health (DBF/RHA) **NO_X and impacts on crops** (yield loss) through formation of **ozone**		Not quantified	Not quantified
TOTAL	**High**	**3672 to 5298 (CL-CH)**	**6096 to 8803 (CL-CH)**
SO_2 as secondary PM_{10} (sulphates) (DBF), (RHA), (CM).	**Medium**	6531 to 41462 (CL-CH)	10842 to 68826 (CL-CH
TOTAL	**Medium**	**6531 to 41462 (CL-CH**	**10842 to 68826 (CL-CH**
NO_X as secondary PM_{10} (nitrates) (DBF), (RHA), (CM).	**Low**	606 to 3848 (CL-CH)	844 to 5355 (CL-CH)
TOTAL	**Low**	**606 to 3848 (CL-CH)**	**844 to 5355 (CL-CH)**
Greenhouse Gas Emissions (CO_2)** Social cost of carbon	**Low**	5193 to 20770	8800 to 35200
TOTAL	**Low GHG**	**5193 to 20770**	**8800 to 35200**
Additional PM_{10} health impacts Respirator symptoms (CA*/A&E/GPv) + Restricted activity days + Respiratory symptoms in asthmatics	**Sensitivity analysis (<u>NOT</u> recommended by COMEAP*)**	7958	13032
NO_X as a gas on health Respiratory Hospital Admissions (RHA)*		0.7	1.0
TOTAL	**Sensitivity**	**7959**	**13033**

See text and previous tables for caveats Note the numbers only include UK benefits.
CL = Central Low. CH = Central High. This range only includes variation in the risk factor for chronic mortality, <u>and</u> the valuation of deaths brought forward and chronic mortality.
For direct comparison, 2010 values assume constant prices, and are not discounted (other than to account for future life years lost).

The values represent the benefits 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.

** The values shown relate to the illustrative range for the social cost of carbon from £35/tC to £140/tC. These benefits have occurred alongside the improvements in air quality, though air quality policies are not directly responsible for these benefits.

The values, by uncertainty band, are presented in the Figures below for annual benefits and total benefits for the evaluation period (1990 – 2001) and projected to occur (2002 – 201).

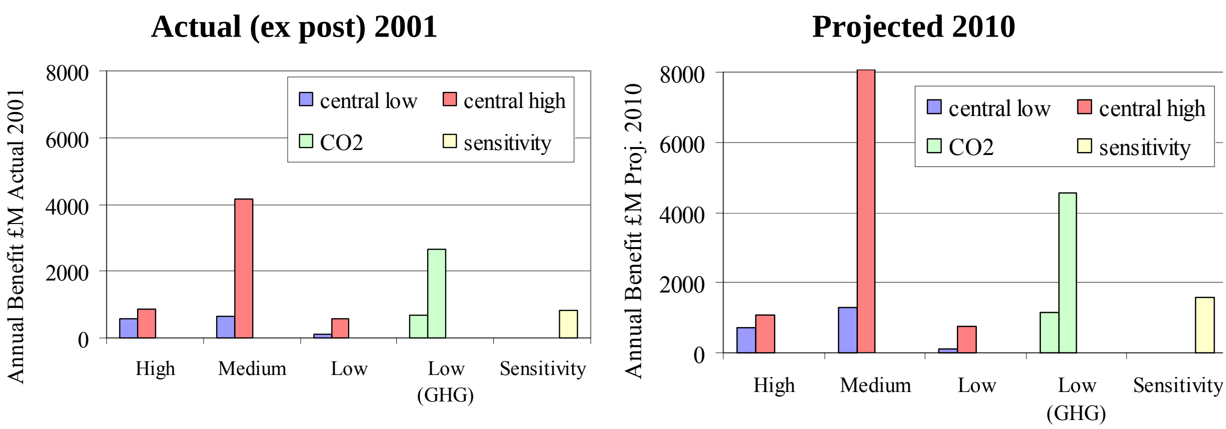


Figure 3-18. <u>Annual</u> Benefits (£M) of ESI Policies Relative to 'No Abatement'. Benefit achieved (in 2001) and Projected to Occur (by 2010), by confidence band

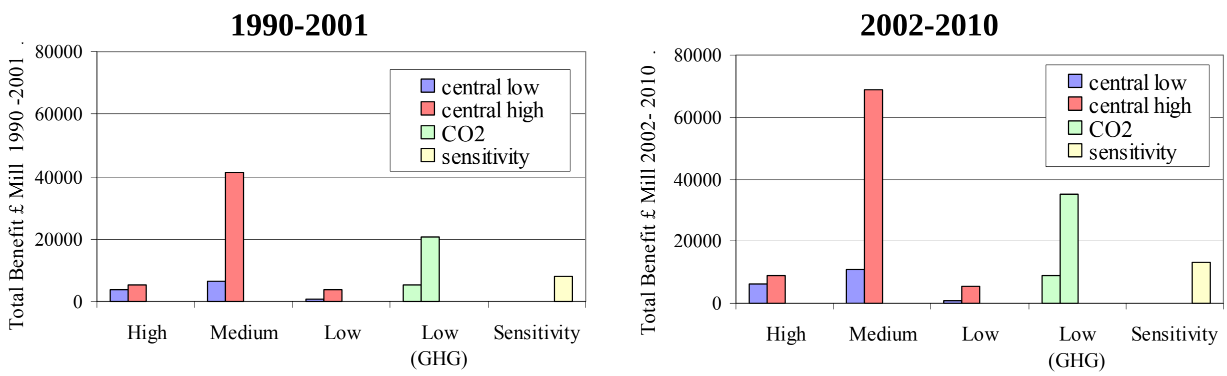


Figure 3-19. <u>Total</u> Benefits (£M) of ESI Policies relative to 'No Abatement'. Benefit achieved (1990-2001) and Projected to Occur (2002-2010), by confidence band

3.4.7. The conclusions for all ESI policies, including energy and environmental policy (i.e. from all air quality benefits in the evaluation period), when compared to the 'no abatement' scenario, are:

- The economic benefits from improvements in <u>air quality</u> in the evaluation period from all policies are extremely large:
  - The annual benefits in 2001 (for high, medium and low confidence bands) are estimated at £1316 million (central low) to £5,589 million (central high).
  - The total benefits in the evaluation period (for high, medium and low bands) are estimated at £10,809 million (central low) to £50,608 million (central high). Note these total 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.
- An analysis by policies shows that between 38 to 100% of these benefits can be attributed to air quality policy.
- Similar benefits are projected to occur in the period 2002-2010, as have occurred in the period 1990 –2001, from improvements in <u>air quality</u> in the ESI:

- o The annual benefits in 2010 (for high, medium and low confidence bands – in 2002 prices, undiscounted) are projected at £2,122 million (central low) to £9,930 million (central high).
- o The total benefits in the projected period (for high, medium and low bands – in 2002 prices, undiscounted) are projected at £17,782 million (central low) to £82,984 million (central high). Note these total benefits are from emissions in the time period 2002 – 2010 only. They do not include benefits from lower emissions in future years (post 2010 for the projected analysis) from a move to sustained new pollution levels.

- 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 shows that the greatest benefits are associated with the medium confidence band, from secondary PM_{10} as sulphates.
- There are significant benefits associated with the low confidence band (nitrates). Note that these effects were estimated as if nitrates have the same toxicity as $PM_{2.5}$ generally.
- There are also significant benefits from CO_2 emission reductions (note not included above) that have occurred at the same time as the air quality benefits. The benefits[55], relative to the no abatement scenario, are estimated at:
  - o The annual CO_2 benefits are estimated at £665 million to £2,660 million by 2001 (the evaluation period), rising to £1,142 million to £4,568 million by 2010.
  - o The total CO_2 benefits in the evaluation period (1990-2001) are projected at £5,193 million to £20,770 million, rising to £8,800 million to £35,200 million as projected in 2002 –2010.
  - o These benefits have occurred alongside the improvements in air quality, though air quality policies <u>are not</u> directly responsible for these benefits.
- The economic benefits of non-health categories (materials and crops) are low in relation to health benefits, though higher as a proportion than for the transport sector. However, the assessment of non-health effects excludes the potential benefits on ecosystems (see later discussion). This is a very important omission and would be expected to increase the non-health benefits very significantly.

3.4.8. The measures in the ESI have achieved a large reduction in the evaluation period (1990 – 2001), but the benefits projected to occur from 2002 – 2010 are larger overall. This occurs because the policies have been introduced over the evaluation period (gradually), and so greater benefits occur in the projected period, because by this time, all policies are in place[56].. The proportion of benefits in the evaluation period is much greater for the ESI than for the transport sector

[55] Estimated using the Government recommended illustrative range for the social cost of carbon of £35/tC to £140/tC. Note the recommended value of the SCC is the subject of a current review. We highlight that the Defra value for the marginal social cost of carbon includes effects in the UK and internationally, i.e. in contrast to the air quality analysis above (which is for the UK only). If the analysis of the marginal social cost of carbon in the UK only was used, this would produce a very much smaller value (almost negligible in fact), since the impact on the UK from changes in the UK's own emissions is practically zero.

[56] Note the benefits in 2001 and 2010 are not quite as might be expected on the basis of the emissions reductions. The emissions analysis shows that by 2001, the emission reductions of SO_2 are already 77% of those expected in the no abatement scenario. We might therefore expect to see less of a difference between the 2001 and 2010 out-turns than shown in the data above. The reason this occurs is due to the modelling of secondary pollution (sulphates) in the no abatement scenario (and due to the reduction in secondary particulates from Europe also reducing the no abatement scenario – as international commitments reduce the amount of pollution 'imported' into the UK).

3.4.9. A comparison with the transport sector shows other interesting results. For primary PM_{10}, the health impact per tonne emitted is very much lower for the ESI than for the transport sector, and so the benefit of emissions reductions is much less in the ESI. I**ndeed, the analysis here shows that the marginal benefit per tonne of primary PM_{10} abated in the transport sector has 50 times the health benefit of primary PM_{10} abated in the ESI**. This is due to the high population weighted exposure from transport emissions, which are emitted at ground level, often 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 air quality improvements.

3.4.10. The sensitivity analysis shows that the additional impacts assessed are important, particularly in relation to the number of health impacts. Indeed, some of the health benefits identified could exceed many million avoided impacts each year, as a result of policies. They are also significant in terms of economic benefits, showing potentially high values compared to other confidence bands.

Benefits of Individual Measures and Policies

3.4.11. The marginal benefits of air quality improvements (e.g. expressed as a cost per tonne of pollutant avoided) have also been used to estimate the benefits of individual policies. The values are presented in the later section on the costs and benefits of specific policies. We have also provided some additional material below, discussing the four major pollutants of concern by policy (PM_{10}, NO_X, SO_2, and CO_2), as these dominate the benefits analysis.

3.4.12. The estimated benefits of policies in reducing **primary PM_{10} only** (directly emitted from power-stations) split by individual measure are shown in the Figure below, relative to the no abatement scenario. The Figure only shows the benefits under the central high scenario. The central low values would be a factor of 6 lower (approximately), but the relative pattern between policies would be identical. Note the values below only include the benefits of emissions in the UK. The figure shows clearly that the benefits achieved to date (to 2001) are large, and that additional benefits projected by 2010 do not increase the overall benefits that much further on an annual basis. In looking at the policies, it is clear that the introduction of the gas into the generation mix has dominated the benefits, though extra PM abatement from power stations (coal) is also important.

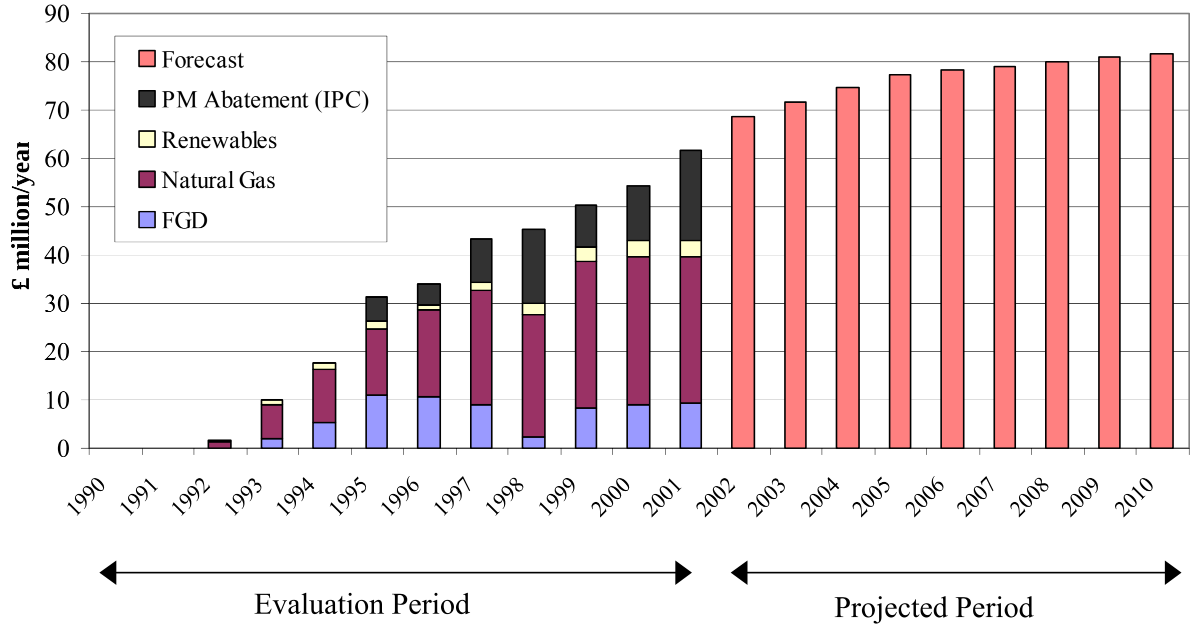


Figure 3-20. Annual Benefits of <u>Primary</u> PM_{10} in the UK from implementation of the ESI Measures over the No abatement Scenario. <u>Central High</u>.

3.4.13. A different pattern emerges for the benefits of **SO_2 emission** reductions, shown for the central high scenario below. This includes the direct effects of SO_2 (on deaths brought forward and RHA) and also the effects of SO_2 on buildings materials (SO_2 is primary pollutant involved in building corrosion). It also includes the formation of secondary PM_{10} (sulphates). The central low values would be a factor of 6 lower (approximately), but the relative pattern between policies would be identical. The benefits are dramatically higher than for primary PM_{10} above – over an order of magnitude higher. The SO_2 benefits dominate the overall benefits from the ESI. Again, the figure shows that the benefits achieved to date (to 2001) are large, and that additional benefits projected by 2010 do not increase the overall benefits much further on an annual basis. This reflects the high SO_2 emissions reductions achieved in the evaluation period. The figure also shows that most benefits have been achieved from the introduction of natural gas, though the combined effect of other measures has also been important. Note the values do not include trans-boundary pollution – this was one of the key drivers in reducing SO_2 emissions. Moreover, the values do not include benefits to ecosystems – again the principle driver for reductions in the evaluation period. The benefits would therefore be expected to be much greater than the values shown below.

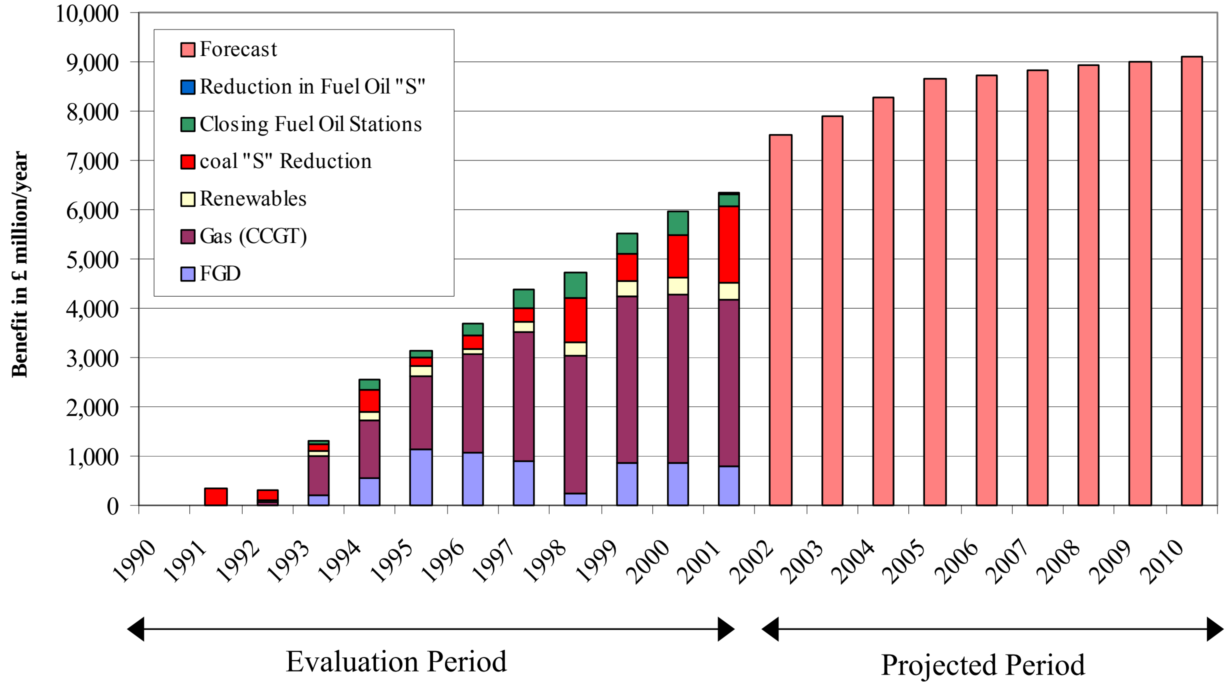


Figure 3-21. Annual UK Benefits of SO_2 from ESI Measures over the No abatement Scenario. <u>Central High</u>. Note includes SO_2 as a gas and secondary PM_{10} (sulphates)

3.4.14. The benefits of the central high scenario are shown in the figure below for **NO_X emission reductions** as the benefits from reducing secondary PM_{10} (nitrates). Note the figure does not include potential effects (positive or negative) from NO_X on ozone. A similar pattern emerges, with most of the annual benefit has been achieved in the evaluation period, though the total benefit will be much greater in the projected period. The introduction of natural gas is responsible for most benefits.

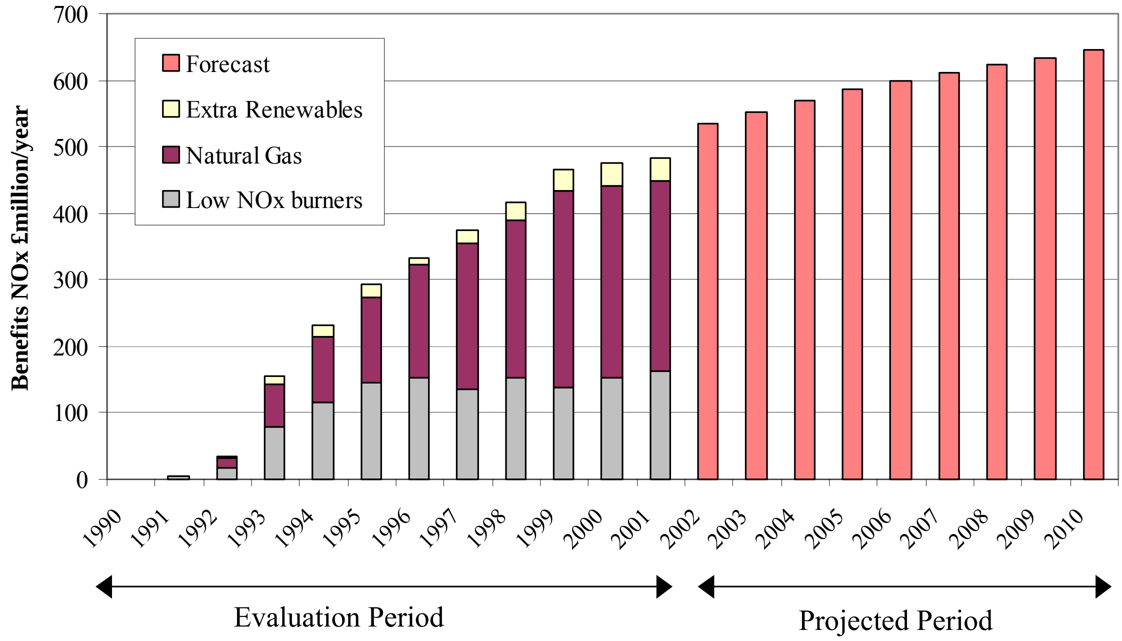


Figure 3-22. Annual Benefits of nitrates (secondary PM_{10}) in UK from implementation of ESI Measures over the No abatement Scenario. <u>Central High</u>.

3.4.15. Finally, we have assessed the benefits of **carbon dioxide (CO_2)** emissions. This is of potential importance given the ESI has been responsible for much of the UK GHG emission reductions seen over the past decade. The values in the summary tables use the illustrative range of £35/tC to £140/tC (increased a £1/tC per year) as recommended in the Government Economic Service (GES) working paper (Clarkson, R. & Deyes, 2002)[57]. The use of the lower end of the range (£35/tC) significantly reduces the importance of CO_2 (see figures below on the environmental costs of generation). The use of the high value (£140/tCO_2) has important implications, as it implies a social cost of carbon that is well in excess to the current cost of generating electricity. We highlight that the value for the social cost of carbon includes both UK and international impacts. This is different to the air quality analysis, which includes UK effects only. If the analysis of the marginal social cost of carbon in the UK only was used, this would produce a very much smaller value (almost negligible in fact) since the impact on the UK from changes in the UK's own emissions is practically zero. The values are summarised below. The CO_2 benefits have occurred alongside the improvements in air quality, though we stress that air quality policies are not directly responsible for these benefits, indeed, we do not believe it appropriate to include these benefits in the summary analysis of air quality benefits. They are, however, needed for comparing the costs and benefits of all policies.

3.4.16. The analysis above has been used to assess the air pollution and carbon environmental costs in the UK. The values are shown below for the central low and central high analysis, in pence per kWh. This shows that the environmental costs of the generation mix in the UK have fallen significantly over the evaluation, and are forecast to continue downwards to 2010. The environmental costs at the start of the decade were extremely large, i.e. they were greater than the cost of generation under both the central low and high analysis. The measures in place in the ESI by 2001 have led to a major reduction in these environmental costs. However, even for the current generation mix (i.e. 2003-4), they show that the environmental costs of electricity generation are significant when compared to the average generation price, and indeed, internalising these cost would increase average electricity prices significantly.

[57] Note the recommended value of the SCC is the subject of a current review.

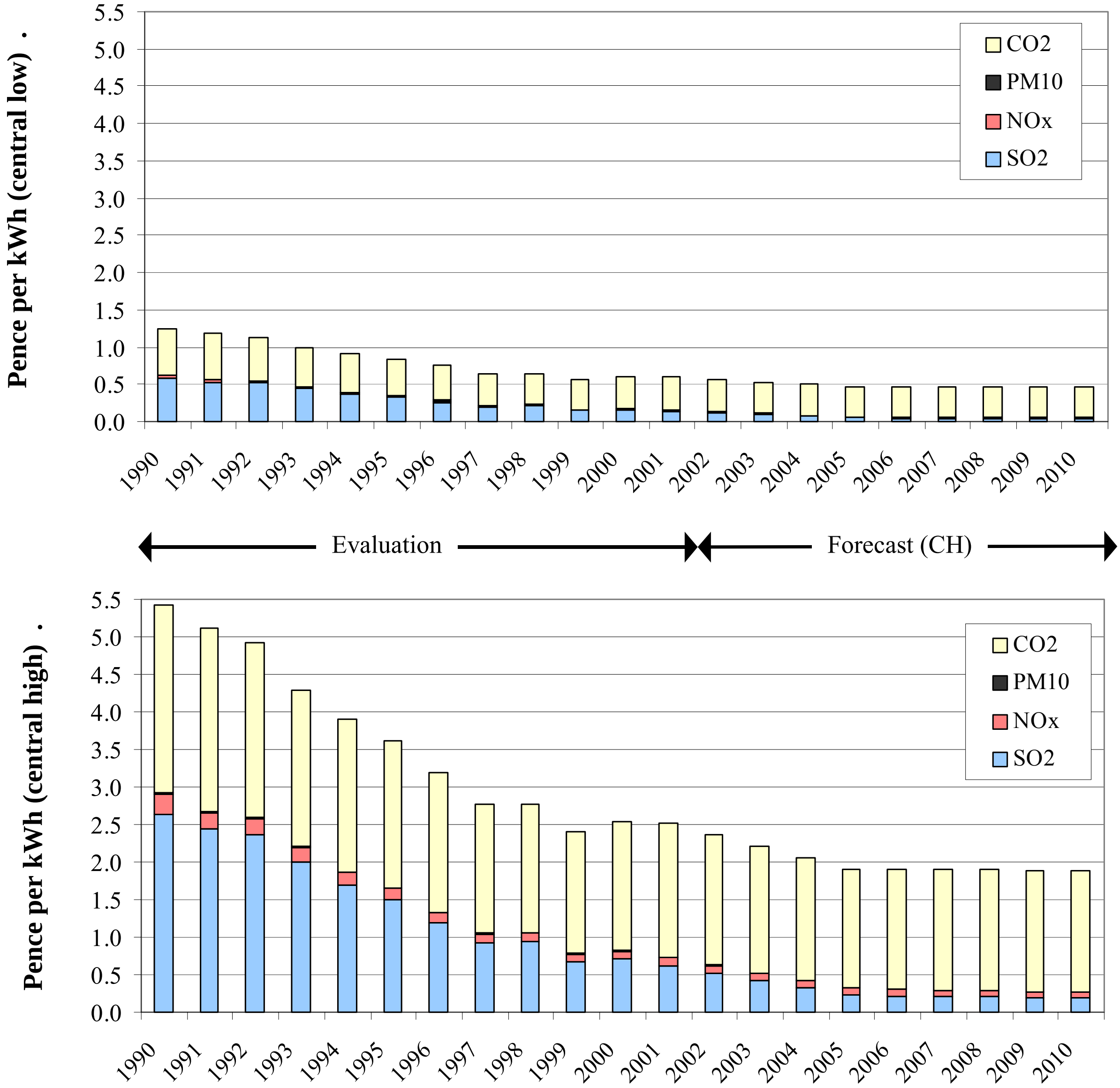


Figure 3-23. Air Pollution and Carbon Social Costs for the UK ESI Top Central Low (Benefits). Bottom Central High (Benefits).

Values are presented as 2002 constant prices. See text for discussion of methodology and valuation.
Values for SO_2 and NO_X include secondary particulates. Note the numbers above do not include the damages from impacts not valued (particularly ecosystems). They only include UK benefits, and do not account for the damages from the reduction in trans-boundary pollution. They do not include the effects of NO_X emissions on ozone formation. They may therefore represent a sub-total of overall costs. Note we highlight that the value for the marginal social cost of carbon (for CO_2) includes effects in the UK and internationally, i.e. in contrast to the air quality analysis above.

Values for CO_2 are based on the SCC illustrative range, with the low value of £35/tC presented alongside the central low value, and the high value of £140/tC presented alongside the central high value.

Table 3-12. Air pollution and climate change costs for the average UK generating mix.

	pence/kWh		
	1990	2001	2010
Air pollution central low	0.62	0.15	0.05
SCC (CO_2) low illustrative value	0.63	0.45	0.41
Total (central low + low SCC)	1.25	0.60	0.46
Air pollution central high	2.92	0.73	0.26
SCC (CO_2) high illustrative value	2.50	1.78	1.63
Total (central high + high SCC)	5.42	2.51	1.89

See notes for Figure 3-23 for caveats.

3.4.17. The table above shows that the current climate change levy (0.43p/kWh) is similar to the illustrative low value for the social cost of carbon (£35/tC) for the average generation mix, but only around one-quarter of the high end of the illustrative SCC values (£140/tC)[58].

3.4.18. Of course, the average generation mix does not reflect the environmental costs from different generation technologies. In the context of air pollution and climate change, the cost of nuclear energy is zero[59]. For most renewables, this is also the case[60]. When fossil fuel technologies are compared:

- Coal fired generation dominates the total environmental costs within the UK ESI. It produces a disproportionately large environmental effect per kWh of power produced.
- The use of oil-fired plants, to supply peak demand, leads to similar damages per unit of power output but overall damages are small due to the low levels of output.
- Natural gas powered generation leads to much lower environmental costs than for other fossil fuels. Even when compared against a modern coal plant with FGD, gas still has much lower environmental costs per unit of power production.

Benefits of Specific Policies

3.4.19. The study has also assessed the benefits of specific policies or targets. The **UNECE sulphur protocols** have been assessed. The protocol is a target, which has to be met by specific national policies, though the choice of how the target is met is up to Member States. The benefits of achieving the protocol in the UK for the central high analysis are shown in the figure below, with direct SO_2 and secondary SO_2 benefits from sulphur reductions for the central high analysis. The analysis shows:

- The annual benefits in 2001 from meeting the protocols are estimated at £1,106 million (central low) to £5055 million (central high), relative to the no abatement scenario. By 2010, these annual benefits are projected to increase to £1,754 million (central low) to £8018 million (central high)

[58] The carbon externalities vary significantly with individual technologies and are highest for coal and oil, slightly lower for gas, and zero for nuclear. These differences are not reflected in the current climate change levy, and even for the low illustrative SCC value (£35/tC) would start to become very significant.
[59] We do not consider other health effects such as arising from radionuclide releases, other social or economic effects not included in the price of nuclear generation, nor life-cycle emissions.
[60] We do not consider other environmental effects, such as loss of amenity through visual intrusion from wind turbines nor life cycle-emissions. Note for a number of renewables, such as waste to energy schemes and biomass plants, there are air emissions, which would have health impacts and would need to be considered.

- The total benefits in the evaluation period (1990 – 2001) are estimated at £7,413 million (central low) to £33,891 million (central high), relative to the no abatement scenario. These are projected to rise to £13631 million (central low) to £62321 million (central high) in the period 2002 – 2010.

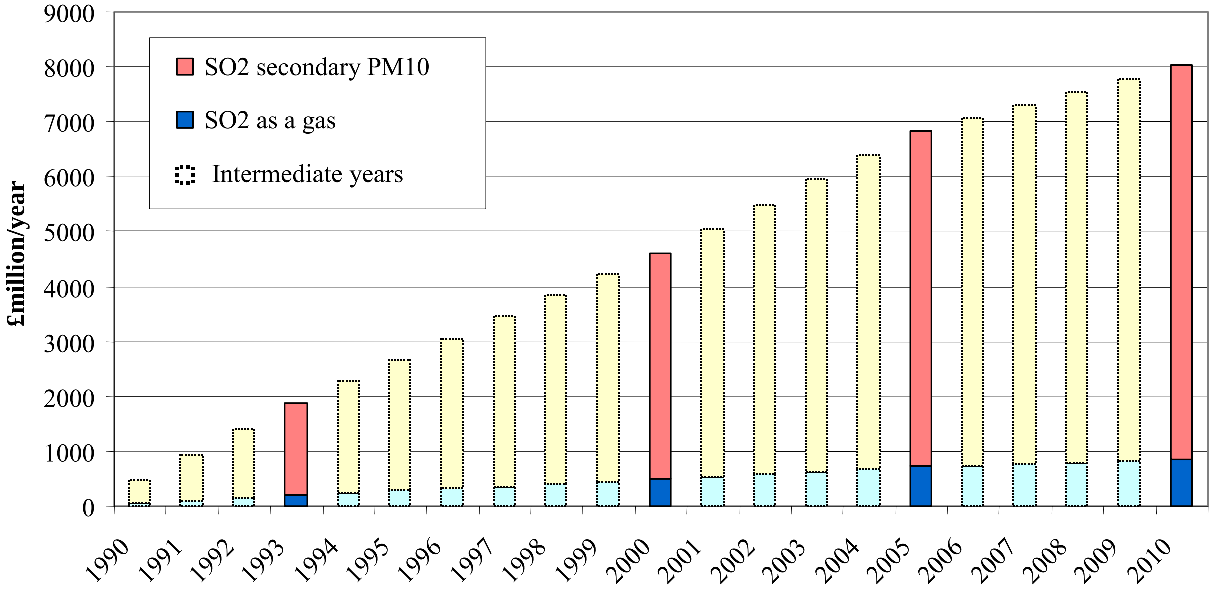


Figure 3-24. Annual Benefits of UNECE 1st and 2nd Sulphur Protocol Relative to No Abatement. Central High. UK benefits only.

Note the numbers above do not include benefits from impacts not valued (particularly ecosystems). They only include UK benefits, and do not account for the benefits from the reduction in trans-boundary pollution.

3.4.20. These numbers are extremely large – they represent the larger benefit from any single air quality policy in the overall study (for both the transport and ESI sectors). It is stressed that these values only include UK benefits – one of the main drivers for the protocol was trans-boundary pollution. They also exclude ecosystem benefits. We therefore expect that the actual benefits are very much higher than shown. However, it can also be argued that the benefits over emphasise the importance of the UNECE protocols. The protocols provided a useful policy objective and also a legal backstop to ensure a minimum level of emissions reduction occurred. The Environmental Protection Act in 1990 required the Environment Agency to apply BATNEEC to control emissions and meet the requirements of international agreements such as the UNECE protocols. The Agency applied whichever of these requirements was the more stringent. Discussion with the Agency indicates that BATNEEC provided the more stringent mechanism for setting emission limits. The question can therefore be asked whether the protocols were actually a driver in reducing emissions? The key issues for generators were the effects of the 'dash' for gas and the extent to which Agency could go beyond the likely outcome in setting emission limits. The sulphur protocols were not a significant feature and indeed, it is likely that a similar outcome could have been achieved in the absence of the protocols.

3.4.21. The first reason that the second UNECE protocol has been met (indeed exceeded) is due to the use of gas for power generation[61]. This has also led to a reduction in other

[61] Note the falls for the first UNECE protocol should not attributed to liberalisation with respect to gas use, because gas generation capacity was still low in 1993.

pollutants (NO_X and PM_{10}). These are shown in the figure below for the central high scenario. The total benefits from the introduction of gas are estimated as:

- The annual benefits in 2001 from the gas are estimated at £784 million (central low) to £3,671 million (central high), relative to the no abatement scenario.
- The total benefits in the evaluation period (1990 – 2001) are estimated at £4,936 million (central low) to £23,125 million (central high), relative to the no abatement scenario.
- Note the SO_2/sulphates benefits are not additional to the UNECE values above.
- There are additional benefits from reductions in CO_2 emissions reductions from gas introduction that would increase these benefits further.

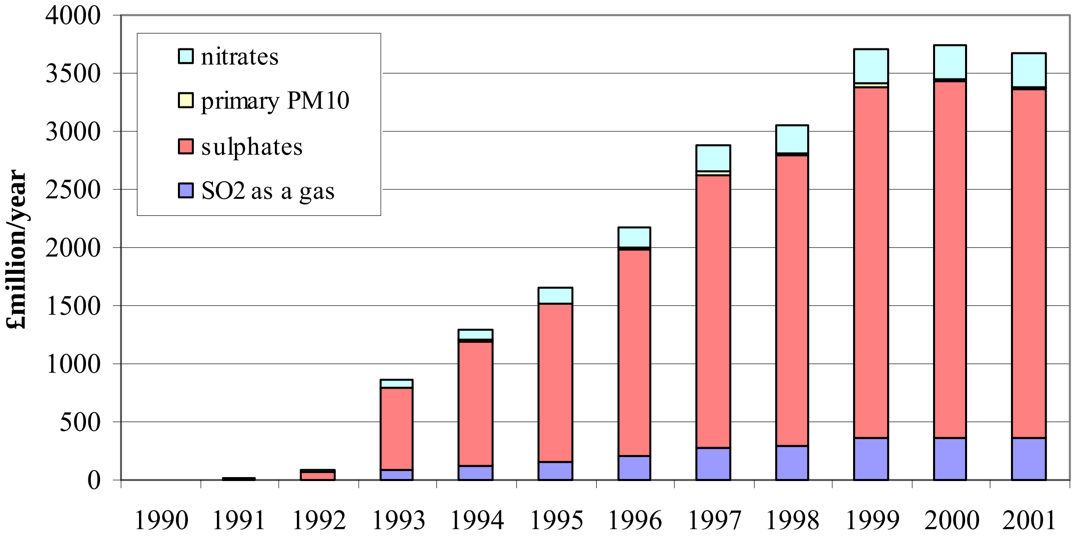


Figure 3-25. Annual Air Quality Benefits of Gas Use relative to No Abatement. Central High. UK benefits only.
Note values for SO_2 / sulphates are NOT additional to UNECE benefits.

Note the numbers above do not include benefits from impacts not valued (particularly ecosystems). They only include UK benefits, and do not account for the benefits from the reduction in trans-boundary pollution. They do not include the effects of NO_X emissions on ozone formation.

3.4.22. As we outline earlier, these benefits should probably be attributed to liberalisation, however, it could also be argued that the use of gas would have been lower if there had not been specific environmental policy in place (e.g. from the LCPD).

3.4.23. The other main reason that the UNECE protocol has been met is because of the measures that have been fitted because of ***Integrated Pollution Control***. This has also targeted other key pollutants, including NO_X and PM_{10}. The figure below shows the benefits that have occurred from IPC related technical measures for the central high scenario. They show that the largest benefits arise from the reduction in secondary PM_{10} from SO_2, though the direct effects in reducing SO_2 as a gas are also high. The most successful individual measure, in terms of benefits, appears to be the use of low sulphur coal, followed by FGD. The total benefits from IPC have been assessed as:

- The annual benefits in 2001 from IPC are estimated at £544 million (central low) to £2,542 million (central high), relative to the no abatement scenario.

- The total benefits in the evaluation period (1990 – 2001) are estimated at £2,914 million (central low) to £13,712 million (central high), relative to the no abatement scenario.
- Note, the benefits of SO_2 reductions are not additional to the UNECE benefits above, but are additional to the benefits from gas introduction.

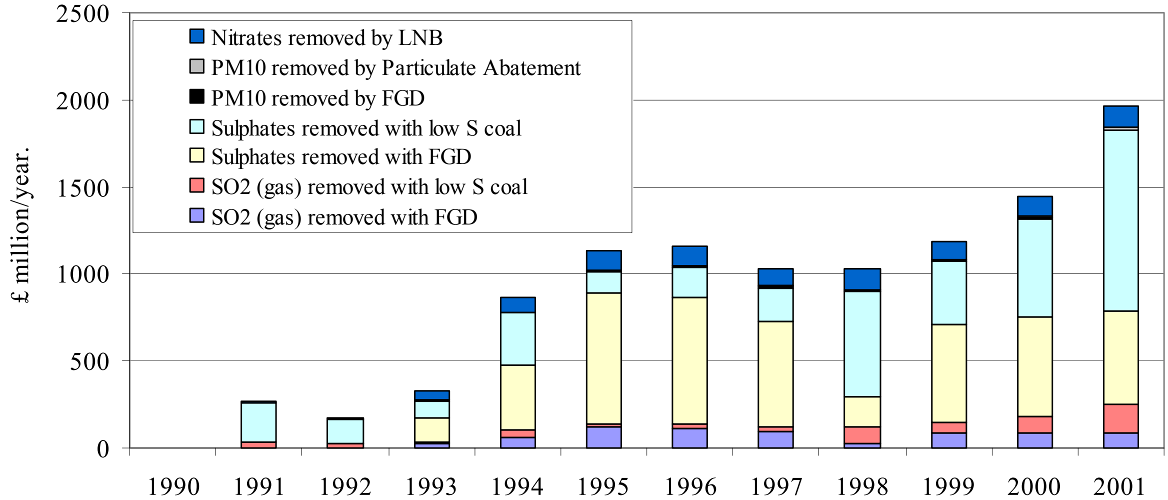


Figure 3-27. Annual Air Quality Benefits of IPC (by pollutant and technology) in UK. Note values include sensitivities (sulphates and nitrates). Central High. UK benefits only.

Note the numbers above do not include benefits from impacts not valued (particularly ecosystems). They only include UK benefits, and do not account for the benefits from the reduction in trans-boundary pollution. They do not include the effects of NO_X emissions on ozone formation.

3.4.24. Finally, the total benefits of ***Renewable Policy*** (the additional renewables over and above 1990 levels, so excluding large-scale hydro) have also been quantified.

- The annual benefits in 2001 from renewables are estimated at £86 million (central low) to £405 million (central high), relative to the no abatement scenario.
- The total benefits in the evaluation period (1990 – 2001) are estimated at £ 498 million (central low) to £2,336 million (central high), relative to the no abatement scenario.

3.4.25. There are additional benefits from reductions in CO_2 emissions reductions from renewables that would increase benefits further. There are also other wider potential benefits (see the policy aims in Box 3.1).

3.4.26. There will be continued benefits from all the above policies in future years. We have undertaken some additional analysis for renewables, given the UK renewable energy target (by 2010, 10% of the UK's electricity should be supplied from renewable sources). The level of benefits will depend on the type of renewables deployed – waste to energy projects and biomass plants both still emit air pollutants – hydro and wind energy do not. Assuming that wind and hydro dominate the future mix, then the estimated air pollution benefits, relative to the no abatement scenario, might rise to around £261 million £1,226 million in 2010. This excludes potential benefits from additional emission reductions of CO_2. Including these CO_2 benefits would increase the benefits values significantly.

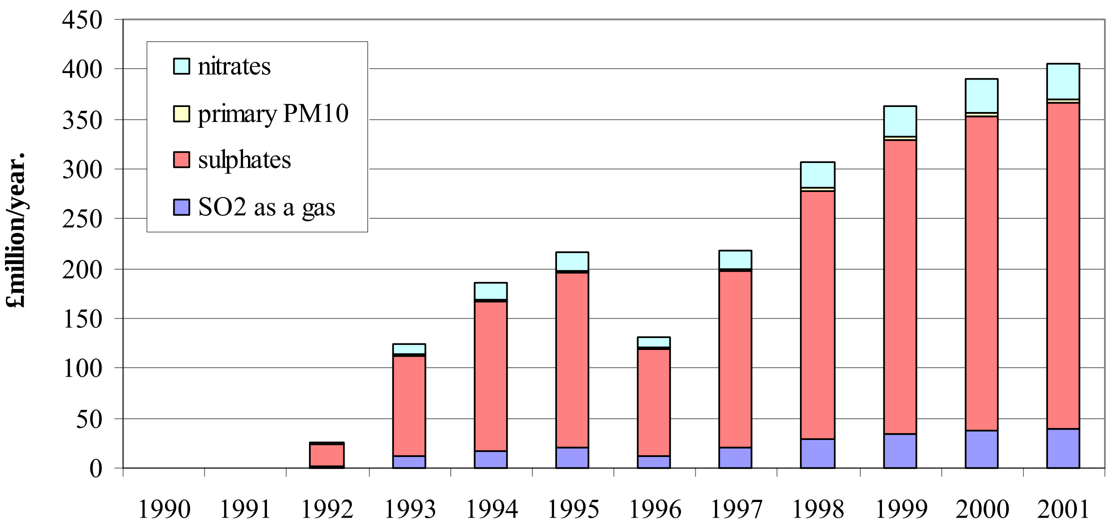


Figure 3-26. Annual Air Quality Benefits of Renewables Policy in UK (including sensitivity of secondary PM_{10}). Central High. UK benefits only.

Note the numbers above do not include benefits from impacts not valued (particularly ecosystems). They only include UK benefits, and do not account for the benefits from the reduction in trans-boundary pollution. They do not include the effects of NO_X emissions on ozone formation.

3.4.27. It is also stressed that not all potential benefits of air quality improvements have been valued (because quantification and valuation is not possible or highly uncertain). The list of effects actually or potentially excluded was presented in the transport chapter. It includes:

- Impacts on ecosystems through exceedence of critical loads and critical levels. The omission of benefits to ecosystems is considered to lead to a significant underestimation of the benefits of the above policies, because of the levels of SO_2 from the ESI. These effects are discussed in more detail in the box below.
- Damage to cultural heritage, such as cathedrals and other fine buildings, statues. Again, we highlight that the strong role of SO_2 in these effects is potential very important for benefits omitted for the ESI.
- Change in visibility (visual range).
- Effects of ozone on materials, particularly rubber.
- Non-ozone effects on agriculture (e.g. through acid deposition, nutrient deposition, etc.).
- Macroeconomic effects of reduced crop yield and damage to building materials.
- Altruistic effects of health impacts.

Box 3.2. Ecosystems Impacts and Valuation

The effects of SO_2 and secondary pollutants on ecosystems ranging from forests to freshwaters are well known, and have been the prime concern until recently in international negotiations. Emissions of NO_X are also known to be responsible for a range of impacts on ecosystems particularly through their contribution to acidification, eutrophication and the generation of tropospheric ozone. However, despite the large, well-documented literature available on these effects, it is not currently possible to conduct an economic analysis of the effects of SO_2 and related secondary pollutants (sulphates and acidity), nor euptrophication or ozone effects on forests, other terrestrial ecosystems and freshwaters, with any confidence. A robust economic analysis would require knowledge of specific effects (change in species richness, productivity, etc.) over extended time scales and appropriate models are not available. Data for valuation of most impacts to ecosystems are also unavailable, or so specific that generalisation to the broader environment cannot be carried out with confidence. In consequence, predictive analysis in this field has almost solely followed the critical levels/critical loads concept.

There has been no direct assessment made of the effects of the policies on ecosystems in this report. However, some indication of the benefits from policies can be drawn from the 2001 NEGTAP Report on Acidification, Eutrophication and Ground Level Ozone in the UK. This estimated the extent of the problem of the exceedence of critical loads for acidification and eutrophication in the UK in 2010. The tables below present estimates of the change in critical load exceedences for acidification and eutrophication in 2010, compared with 1995 to 1997, following the implementation of policies (notably full implementation of the Gothenburg protocol). For acidification of ecosystems, the area of critical load exceedences is estimated to fall from 71% to 46% compared to 1995-97. For eutrophication by nitrogen, exceedence of critical loads of ecosystems are estimated to fall from 40% to 32% compared to 1995-97. The benefits from policies since 1990 will be very much greater.

UK	**Percentage of ecosystem areas exceeding critical loads for ACIDITY**		**Percentage exceedences of critical loads of ecosystems for EUTROPHICATION by nitrogen**	
Ecosystem Type	**1995 to 1997**	**2010**	**1995 to 1997**	**2010**
Acid grassland	80	52	27	19
Calcareous grassland	32	18		
Heathland	69	49	56	42
Coniferous woodland	69	38	88	79
Deciduous woodland	82	68	96	92
Freshwaters	18	9		
All ecosystems	**71**	**46**	**40**	**32**

Source: NEGTAP, 2001.

Ideally it would be possible to go beyond this, to describe impacts (and value them) for different types of ecosystems. However, whilst information from the literature provides insight on the types of effect that may be anticipated, there is no sound basis at the present time for further quantification. However, continued omission of monetised ecosystem damages means that there is a significant bias towards underestimation of total damages.

UNECE NEBEI (Network of Experts on Benefits and Economic Instruments) convened a workshop to discuss issues of ecosystem valuation, largely (though not exclusively) in the context of air pollution. The Working Group stated that the benefits estimation should complement, rather than replace, other techniques for reporting ecological risks. Under the EC DG Research NewExt project an attempt has been made to infer the value placed on ecosystem protection by looking at how far decision makers were prepared to go in restricting emissions under the National Emission Ceilings Directive and the Gothenberg Protocol. This ‘standard price’ or ‘control cost’ approach permits calculation of a cost per hectare no longer subject to critical loads exceedence. Problems with this technique have been widely reviewed before and it is not recommended in cost-benefit analysis (because of circular reasoning). Finally, there has been some work to assess the total economic value of ecosystems (the sum of the use value and the non-use value). Ruijgrok (2003) provided analysis for the Netherlands, estimating the use and non-use values (using contingent valuation) for ecosystem damage from acidification in the Netherlands at €200 million per year. Whilst this indicates that some degree of valuation is possible, it still leaves elements unquantified. However, it does indicate that the potential benefits of policies in the ESI, relative to the counter-factual, could have been very large – at least of the same order of magnitude as the benefits from SO2 reductions on other impact categories.

3.5 Economic Costs of the Policies

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

Costs of the UNECE protocols

3.5.2. The UK initially refused to accept the 30% reduction required under the UNECE's first sulphur protocol. Various reasons were given by the government of the time for not signing up to the "30% Club" under the Helsinki Protocol, including:

- That the base year against which emission reductions would be compared (1980) already included a significant fall in UK emissions compared to the previous year. Using this as the base year therefore gave no credit to the UK for savings already made, and so posed an unreasonable financial liability on the country.
- It did not accept the scientific data accumulating on the acid rain problem as proof that UK emissions damaged ecosystems across the continent.
- It did not accept the concept of uniform % emission reduction targets, as emissions in some locations were likely to be more harmful than others.

3.5.3. The SEI (1999) report, produced for the Swedish Ministry of the Environment, reviewed the ex ante costs of the UNECE Protocols on acidification and the 1988 Large Combustion Plant Directive from the European Commission. The paper cites UK industry (CEGB) who produced ex ante estimates that forecast increases in generating costs of up to 30% and increases in electricity prices by as much as 25%. These costs estimates were based on the assumption that plant would be fitted with flue gas desulphurisation equipment to meet the regulations[62]. In contrast, a non-industry source estimated that costs would increase by a smaller amount, only 2.5% to 5% over a 15 year period. However, other policies being implemented, such as liberalisation of energy markets had a very major impact on national emissions[63]. So much so that UK emissions of SO_2 in 1993 (the target year) had fallen by 36% compared to 1980. Note these falls should not attributed to liberalisation with respect to gas use, because gas generation capacity was still low in 1993. However, gas use is one of the major reasons that the UK is likely to meet the 2nd S protocol and intermediate targets.

3.5.4. Note in Germany, where there was no equivalent dash for gas, ex ante analysis of the first UNECE S protocol by the Government (through the Umweltbundesamt, or UBA) was criticised by industry as being a factor of 2 too small. Ex post analysis after 1988 revealed that the UBA estimates were too low, but by a factor of only 1.25. In contrast to the UK (where privitisation masked the ex post out-turns), this indicates that there was some over-estimation of ex ante costs of the protocol.

Costs of Renewable Policy

3.5.5. The issue of ex ante and ex post costs are less relevant for Renewable Policy**,** as NFFO was a market support mechanism (subsidy), rather than a policy. It would be expected that

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62 In fact, only two of the country's coal fired power stations, Drax and Ratcliffe-on-Soar, were operating with FGD by the later 1990s, the technique originally seem as key to meeting major reductions in UK SO_2 emissions.

63 The major generators of the time, National Power and PowerGen, intended to comply with their obligations through a policy of switching to natural gas and lower sulphur imported coal, rather than through the more costly FGD programme originally proposed by the CEGB before privatisation.

the NFFO bid prices (ex ante) were in very close agreement with the actual costs of generation (ex post). It might be possible to assess whether this has been the case, though this would require a more detailed analysis than possible in the present study. Ex post data is available of the costs of NFFO rounds. NFFO has been increasingly heavily over-subscribed, and its key success has been in reducing the price of renewable electricity from some 7p/kWh in the first two Orders to only 2.71p/kWh in the 5th Order. This price can be compared to the average spot price for all electricity of around 2.5p/kWh in 1998, and an average purchase price paid by RECs of 3.5p/kWh. More details on the costs of NFFO are presented in the next section (comparing costs and benefits). The details of the average price for subsequent rounds is shown in the Table below

Table 3-13. Capacity and Average Price of NFFO rounds.

	Capacity awarded (MW DNC)	Capacity deployed (MW DNC)	Average price (p/kWh)
NFFO 1	152	145	7.0
NFFO 2	472	174	7.2
NFFO 3	627	191	4.35
NFFO 4	843	18	3.46
NFFO 5	1177	0	2.71

MW DNC = declared net capacity in megawatts
Source: Evaluation of the DTI New and Renewable Energy Programme.1994-8 Final Report. SPRU (1999).

3.5.6. In terms of the costs of the policy, the Non-Fossil Fuel Obligation provided over £600 million of support for renewables from introduction through to 1998/99, and support for renewables amounted to about £130 million in the financial year 1998/99 (i.e. the above market costs)[64]. There was also an additional support for the New and Renewables Programme, which included R&D and dissemination to assist those technologies with prospects of market penetration. This had an expenditure of around £26 million/year in 1992/93, rising to £11 million/year 1997/98. Total expenditure between financial years 1994/95 - 1997/98 was £62 million and cumulative to 1999 was around £80 million.

Costs of Integrated Pollution Control

3.5.7. Less data is available on the overall costs of Integrated Pollution Control. Instead, we have assessed the various 'ex ante' and 'ex post' costs of technical measures as implemented in IPC, to try to assess the potential costs that would have been predicted in appraisal, and have occurred as an actual out-turn. We have reviewed 35 studies that have reported ex ante or ex post costs for the ESI, from 1975 through to the current time. Most of these studies were undertaken in the period 1995 –1999, due to the focus on regulatory impact assessment and policy implementation during this period. The pattern of cost studies, by time period, are shown in the Figure below.

[64] DTI New & Renewable Energy Prospects for the 21st Century (1999).

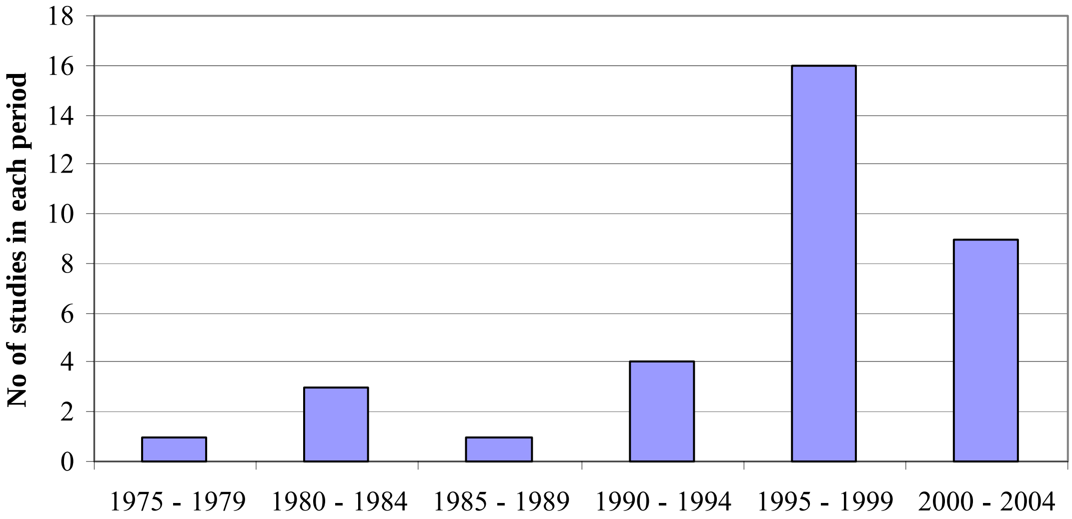

Figure 3-29. Age of Studies Assessed for Ex Ante and Ex Post of Technical Options.

3.5.8. In general, we have found that the earlier studies report 'ex ante' estimates of technologies relevant to IPC, and the later studies report 'ex post' estimates from options actually implemented. A summary of the findings of the review are presented below:

- **Flue Gas De-Sulphurisation.** FGD has been used in the UK for many decades. Clinch (1955) reports that such systems were used in London at Battersea, Fulham and Bankside power stations and also came up with some of the earliest damage costs for SO_2[65]. More recent estimates are, of course, available. The early ex ante estimates (e.g. CEGB, 1979) estimated a 25% increase in electricity generation costs at power stations due to FGD. A few years later (e.g. ERL, 1983), ex ante estimates had fallen to a value of a 10-20% increase in generation costs, and Highton (1984) estimated an increase of 2.5 – 5%. The estimated unit costs, per tonne of SO_2 abated, have fallen dramatically over the period. However, more recent studies, including work for the Environment Agency, now indicate that costs may rise (at least per tonne of SO_2 abated), because coal plant load factors are dropping, thus costs of installation are high when spread across the levels of SO_2 abated.
- There are a number of studies looking at **NO_X abatement costs** (e.g. low NO_X burners and selective catalytic reduction (SCR)). There is a general trend towards a reduction in the costs from earlier to later studies, though the scale of reduction is relatively low compared to other technologies targeting other pollutants.
- There is some analysis of the 'ex ante' and 'ex post' out-turns from **Low Sulphur Fuel.** Earlier studies (e.g. AEA Technology Environment, 1994) concluded that (ex ante) the use of low sulphur coal was more economically attractive than installation of FGD for all sizes of coal fired plant. More recent studies have actually shown even lower 'ex post 'out-turns. For example, the estimated costs of using 1% S coal have fallen from something in excess of £250 / tonne of SO_2 removed down to a value of zero (Entec, 2000).

[65] Costs of the Fulham system were reported as being 10 shillings per tonne of coal burnt, equivalent to £290/tonne of SO_2 released in 2002 prices. Costs at Battersea and Bankside were lower at around £245/tonne of SO_2 released. Clinch noted that at these prices the British Electricity Association would be unlikely to be willing to adopt these technologies as a general policy. FGD fell out of use in the UK as the old power stations closed down and new ones were built outside the major cities in areas such as the Trent Valley. The Clinch paper also includes a very early estimate of SO_2 damage, of between 3s. 4d. (17p) and 8s. 4d. (42p) per ton of coal burnt, with the assessment probably limited to damage to building materials. Adjusting for inflation and the sulphur content of coal typical of 1955 provides a range of £100 to £250/tonne of SO_2.

3.5.9. Overall, there is a broad trend of very early studies providing very high costs for abatement equipment. The ex post costs have generally been significantly lower than predicted in earlier ex ante studies. A summary of some of the literature values are presented in the table below.

Table 3-14. A Selection of Literature Costs of Abetment for Large Plant.

Measures	Abatement Cost
Replacement of 1.6% S coal with 1% S coal 1% S coal	252 £/t SO_2 (AEA, 1994) Zero (Entec, 2000)
Replace coal plant with existing CCGT	-49 £/t SO_2 (AEA, 1994)
Replace coal plant with new CCGT	453 £/t SO_2 (AEA, 1994)
Replacement of 3% S oil with 1% S coal	443 £/t SO_2 (AEA, 1994)
Replace oil plant with existing CCGT	-106 £/t SO_2 (AEA, 1994)
Replace oil plant with new CCGT	308 £/t SO_2 (AEA, 1994)
FGD increase in generation costs FGD increase in generation costs FGD increase in generation costs	25% CEGB (1979) 10-20% ERL (1983) 2.5-5% Highton (1984)
FGD FGD	407 £/t SO_2 (AEA, 1994) 300 £/t SO_2 (ERL,1996)
Low NO_X burners Low NO_X burners Low NO_X burners Low NO_X burners	43-258 £/t NO_X (FoEng, 1991) 132 £/t NO_X (FoEng, 1991) 94 £/t NO_X (AEA, 1994) 140 £/t NO_X (ERL, 1996)
SCR SCR SCR	557-1900 £/t NO_X (FoEng, 1991) 597 £/t NO_X (AEA, 1994) 800 £/t NO_X (ERL,1996)

Note the table presents original cost data, without adjustment. When the values are converted into equivalent current prices, the trend towards lower costs in later years is strengthened. The studies assume widely different assumptions about discount rate, plant efficiency, operational lifetime, and so direct comparisons should be treated with caution.

Costs of National Emissions Ceiling Directive and the Gothenburg Protocol

3.5.10. Sulphur controls under the National Emission Ceilings Directive and Gothenburg Protocol. The EU's National Emission Ceilings Directive (NECD) and the UNECE's Gothenburg Protocol were developed over the period 1996 to 2001. This process included extensive use of the RAINS model by the International Institute for Applied Systems Analysis (IIASA), which optimises emission strategies for each European country against pre-set targets for acidification, eutrophication and ground level ozone. This work was also backed up with cost-benefit analysis carried out by AEA Technology Environment for the EU, and in the closing stages of the negotiations for the UK. The results for SO_2 controls for the later IIASA analysis (6th interim report to 8th interim report) are compared with results from cost-effectiveness analysis carried out by AEA Technology in 1999 and then in 2001 below. They show that estimates fell substantially through the 3 series of analysis, with the IIASA analysis giving costs roughly twice as large as the AEA Technology 1999 assessment, and about 10 times higher than the AEA Technology 2001 results[66]. Comparison of results for NOx

[66] The RIA for the NECE estimated that if the implementation of the LCPD will deliver the UK's sulphur dioxide ceiling the cost of NECD will be negligible. However if additional measures are required to meet the SO2 ceiling the cost of going beyond LCPD could be as much as £29M per annum (Entec, 2002).

reductions is not possible, as the changes in UK emissions of NOx that were investigated during the analyses were insignificant.

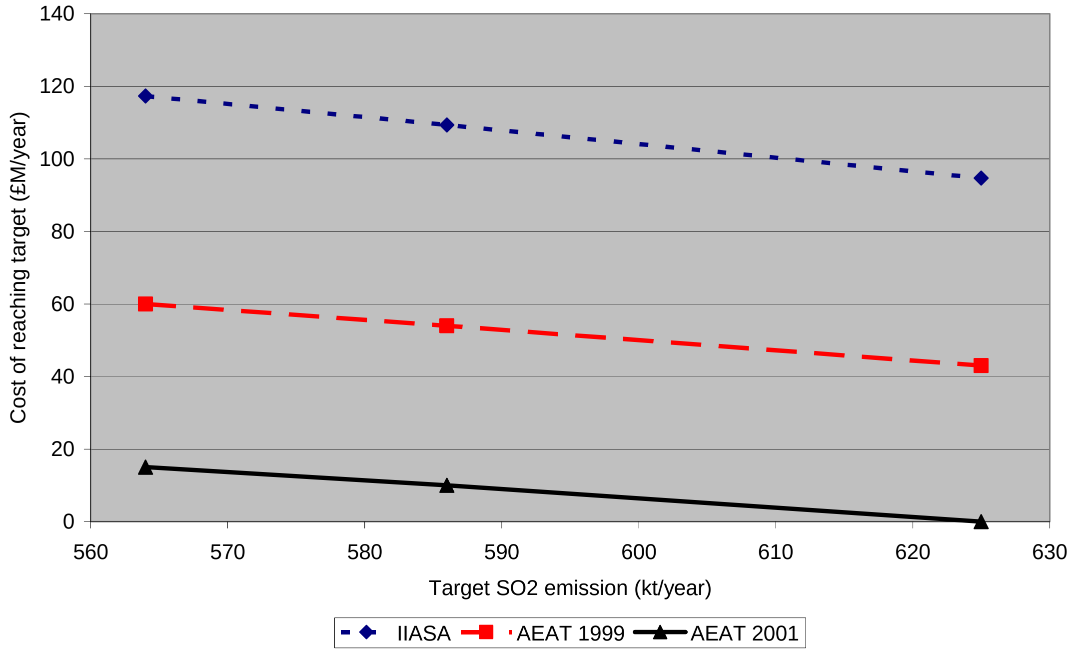

Figure 3-30. Change in Ex Ante Cost Estimates (in Appraisal) for the UK to meet emission ceiling targets for the UK in 2010.

3.5.11. There were several significant differences between the assessments carried out by AEA Technology and IIASA. The most important were:

- Estimated baseline emissions for SO_2 in the UK in the year 2010 (the target year for both Directive and Protocol) fell first from 980 kt/year to 784 kt/year, and then to 612 kt/year. In all cases baseline emissions were based on DTI's Central/High scenario from Energy Paper 65 and (later) Energy Paper 68. Falling emissions not only reduced the amount by which SO_2 emissions needed to be cut, but also reduced the need to include higher cost measures. Of the two effects it is the first, the cut in additional abatement required, that makes the greatest difference. A similar pattern was found for emissions of VOCs. Estimated emissions of NOx and NH_3 remained reasonably constant throughout. The change in emissions was not a result of changes in legislation during the development of the Directive and Protocol. It seems that the more important factor was simply changes in assumed fuel mix for 2010, with a move away from high sulphur coal and oil to natural gas in particular.
- A second major difference was that changes were made to the estimated efficiency of flue gas desulphurisation (FGD) in UK coal fired power stations. However, for the analysis carried out by AEA Technology it was assumed that FGD efficiency at UK power stations was lower than that assumed by IIASA, on account of the load factors typical of the UK plant with the effect of *increasing* the costs of abatement. The difference between the initial estimates and the later estimates would thus have been even greater had a higher efficiency been assumed.

3.5.12. This case study thus highlights an example where the critical factor in determining abatement costs is the market forces determining the choice of fuel used. It is unusual in that technological costs rose during the assessments, though to a relatively limited extent compared to the effects of falling baseline emissions.

Table 3-15. Changes in UK baseline emissions for SO_2 and other pollutants during analysis of possible emission ceilings for the UK.

Scenario	SO_2	NOx	VOC	NH_3	Reasons for change
IIASA Reference	980	1186	1351	297	Implementation of various national and EU regulations on emissions.
UKREF1 (AEAT, 1999)	784	1187	1336	319/ 297	Fall in emissions based on draft of DTI Working Paper. Range for NH_3 reflects uncertainty.
UKREF2 (first draft AEAT 2001)	612	1167	1252	319/ 297	Emissions revised following new DTI energy projections (DTI, 2000).
UKREF3 (second draft AEAT 2001)	612	1167	1200	297	VOCs, NH_3 reduced to Gothenburg Protocol ceilings.
UKREF4 (AEAT, 2001, final)	612	1167	1152	297	VOCs further reduced following discussions with BCF and UKPIA.

Costs of the revised Large Combustion Plant Directive

3.5.13. A number of appraisals (ex ante) studies have been made of the revised Large Combustion Plant Directive**.** Entec (2000) provided an assessment of the costs to the UK of the revised Large Combustion Plant Directive as it stood in early 2000. Entec concluded that the targets for sulphur would dominate costs to the UK. Specific measures would not be required for compliance with the targets for particles or NOx. The most cost-effective approach for reducing sulphur emissions would be fuel switching, though this would not be enough on its own to meet the targets. The next most cost-effective option was plant closure, considering the age of many large combustion plants in the UK, and the limited load factors applying to certain of them. In some cases the avoided cost of not bringing plant up to IPPC standards was estimated to be more than enough to offset the costs of replacement investment, particularly where remaining plant lifetime was short. Depending on the precise strategy adopted for compliance, Entec estimated that costs would be between *minus* £38 million and *plus* £244 million in present value terms. These costs related to four scenarios that assumed full compliance with IPPC by 2010.

3.5.14. The study has also investigated the wider economic impacts of air quality policy in the ESI. The lack of ex ante and ex post analysis makes it difficult to draw robust conclusions on the extent of the wider economic effects that may have resulted from the imposition of the electricity sector-related air quality policies. This difficulty is compounded by the fact that wider economic effects have occurred as a result of liberalisation policy and fuel switching. It is difficult to separate out the causes of possible competitiveness and employment effects from other changes in the industry including general electricity market liberalisation within UK and these wider effects have been agreed to be outside the current project scope (e.g. the employment effects associated with a switch away from UK coal production).

3.5.15. There have been some scoping studies that have looked at the potential employment effects from wider air pollution legislation or renewables. These do not generally undertake detailed modelling of wider economic costs (the expense involved in undertaking comprehensive analysis of these effects through general equilibrium modelling is not justified by the potential findings of such studies).

3.5.16. Overall, the costs of generating electricity over the evaluation period have actually fallen in real terms (for industrial and domestic consumers). This is in contrast to most of the ex ante predictions of the legislation, which forecast price increases, some very significant (e.g. as for the UNECE protocols above)[67]. A summary of the costs for each policy is included in the table in the next section.

3.6 The Comparison of Costs and Benefits

Summary of individual policies

3.6.1. The overall costs and benefits of policies are brought together in the table below. We stress that because policies have different implementation dates, the absolute costs and benefits will appear very different for different policies in the evaluation period. To illustrate, the UNECE protocol has been in force for the entire evaluation period, while other policies or measures have only come into force later in the decade.

[67] It is still possible that technology costs or generation costs have risen over the period, but any increases have been masked by the electricity liberalisation and competition.

Table 3-16. Costs and Benefits of Electricity Generation Policies in the UK for Evaluation Period (1990 – 2001).

	Ex Ante Costs			Ex Post Costs		AQ Benefits
Policy	**Unit cost (£)**	**Annual Cost (£ Mill.)**	**Total Cost 1990 – 2001 (£ Mill.)**	**Unit cost**	**Total Cost 1990 –2001 (£ Mill.)**	**1990 –2001 (£ Mill)**
UNECE						
1st Sulphur Protocol	1980 estimated increase in generating costs up 30% and electricity prices 25%. Largely assumed would be met through use of FGD	1) Based on 30% increase in costs, estimated imply costs of = £2647 M 2) Based on FGD unit costs, and targets levels, imply cost of = £687 M	1) Based on 30% increase in costs = £28905 M 2) Based on FGD unit costs = £4609 M	Later estimates electricity costs only rise by 2.5% to 5% (ex ante, 1984) MARKAL out-turn (2002) indicates extra 0.16 p/kWh = 10% increase on costs for coal plant with FGD	Minimum, zero. Maximum based on 5% increase in generation costs = £4818 M	Benefits within evaluation period Assumed meet 50% reduction by 1993 and maintained = Total Benefits 1990-1993, plus 1993 levels maintained to 2001= £4334 M to £19813M (CL to CH).
2nd Sulphur Protocol		Around £100 M/year (IIASA, 1994)		Estimated to be zero – 29 M per year in latest ex ante analysis (AEAT).		Additional benefits from 2nd UNECE in period 1994-2001= £ 3079 M to £ 14078 M (CL to CH). Total UNECE 1 and 2 1990 to 2001 = £7413 M to £33891 M (CL to CH) Full target date 2010. Additional benefits 2002-2010 = £13631 M to £62321 M (CL to CH)
Environment policy						
Reduction in Fuel Oil "S" content	Cost refiners an estimated £55-125 million per year, with a further £12 million compliance cost (Entec, 2002)– but costs for all sectors – includes refineries, industrial boilers, large ships and a few power stations			Not within evaluation period (though some early moves towards compliance, and analysed for 2001)		£13 M to £59 M in year 2001 (CL to CH)

All benefits are presented in 2002 prices with no discounting to allow direct comparison. Note 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. The table includes the benefits categorised under high, medium and low confidence bands, but excludes those included in the sensitivity analysis. The values only include UK benefits, and do not account for the benefits from the reduction in trans-boundary pollution. Environmental benefits do not include all benefits, with a number of areas excluded including impacts on natural and semi-natural ecosystems (terrestrial and aquatic), impacts on forests, visibility, and others (see main text). The analysis does not include the effects of NO_X emissions on ozone formation.

Table 3-16. Costs and Benefits of Electricity Generation Policies in the UK for Evaluation Period (1990 – 2001). Continued

	Ex Ante Costs			Ex Post Costs		AQ Benefits
Policy	**Unit cost (£)**	**Annual Cost (£ Mill.)**	**Total Cost 1990 – 2001 (£ Mill.)**	**Unit cost**	**Total Cost 1990 –2001 (£ Mill.)**	**1990 –2001 (£ Mill)**
IPC						
Low sulphur coal	£250/tSO_2 removed.	Annual costs of £130 million/year by 2001 on cost per tonne basis	Estimate as £484 million for evaluation period on cost per tonne basis	Estimated as zero		£1246 M to £5694 M (CL to CH)
FGD	1994 estimated around £400/tSO_2	Around £110 million per year on cost per tonne basis	Estimate as £900 million for evaluation period on cost per tonne basis	Later estimates indicate cost per tonne £300/tSO_2 (but still ex ante) MARKAL out-turn indicates extra 0.16 p/kWh for FGD = 10% increase on coal plant generation cost	Ex post cost estimates for 2 early FGD plant in the UK are £685 M for Drax and £250 M for Radcliffe. Current cost estimates for a 2 MW plant are around £100 M	£1459 M to £6990 M (CL to CH)
Low NOx burners	Around £140/tNO_X (1991)	Around £23 million on cost per tonne basis	Estimated as £180 million for evaluation period on cost per tonne basis	Later estimates (1994) £65/tNO_X	Estimated as £83 million for evaluation period on cost per tonne basis	£198 M to £1255 M (CL to CH)
Particulate abatement	0.04 p/kWh ESP, 0.04 p/kWh fabric filter (1995)			0.02-0.03 p/kWh for ESP (O&M, 2000)		£11 M to £73 M (CL to CH)
All IPC measures (sum)						**£2914 M to £13712 M (CL to CH)**

See notes above.

Note the costs and benefits of IPC measures (from SO_2) are not additional to the UNECE protocol above.

Table 3-16. Costs and Benefits of Electricity Generation Policies in the UK for Evaluation Period (1990 – 2001). Continued

	Ex Ante Costs			Ex Post Costs		AQ Benefits
Policy	**Unit cost (£)**	**Annual Cost (£ Mill.)**	**Total Cost 1990 – 2001 (£ Mill.)**	**Unit cost**	**Total Cost 1990 –2001 (£ Mill.)**	**1990 –2001 (£ Mill)**
Renewables						
NFFO	No estimates	No estimates	No estimates	Annual £130 million in the year 1998/99. Total £600 million up to 1998/99		£498 to £2336
Energy Policy						
Closing Fuel Oil Stations						£547 M to £2502 M (CL to CH)
Natural gas						£4936 M to £23125 M (CL to CH)
TOTAL						
All policies						£10809 M to £50608 M (CL to CH)

See notes above.

Note the costs and benefits of natural gas (from SO_2) are not additional to the UNECE protocol above.

Summary of all policies

3.6.2. The costs and benefits of policies are summarised in the table below. Note the costs and benefits of IPC measures are not additional to the UNECE protocol.

Table 3-17. Summary of Present Values for Ex Ante Costs, Ex Post Costs and Ex Post Benefits of ESI Policies in the Evaluation Period (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			**£10809 M to £50608 M (CL to CH**

The table includes the benefits categorised under high, medium and low confidence bands, but excludes those included in the sensitivity analysis and excludes CO_2 benefits. 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 will appear very different for different policies in the evaluation period.

Note these total 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.

3.6.3. It is also interesting to look at the ratio of benefits to costs, for all policies. The comparison of benefits against ex ante costs is shown below. A value of greater than one indicates a favourable policy (i.e. it shows benefits exceed costs).

Table 3-18. Benefit to Ex Ante Cost Ratio for ESI Policies

	Ratio of Benefit : low ex ante cost		**Ratio of Benefit : high ex ante cost**	
	Where benefits = central low	Where benefits = central high	Where benefits = central low	Where benefits = central high
UNECE				
1st Sulphur Protocol	0.9	4.3	0.1	0.7
2nd Sulphur Protocol	3.8	18.4	3.8	18.4
Environment policy				
Reduction in Fuel Oil "S" content	0.2	1.1	0.1	0.5
IPC				
Low sulphur coal	2.6	11.8	2.6	11.8
FGD	1.6	7.8	1.6	7.8
Low NOx burners	1.1	7.0	1.1	7.0
Particulate abatement				

Note the costs and benefit of IPC measures are not additional to the UNECE protocol.

Benefits value excludes CO_2 benefits and benefits outside the UK.

3.6.4. It is much harder to do this with confidence for the ex post costs. Where ex post data has been found, the ex post benefit: cost ratio increases dramatically, shown below.

Table 3-19. Benefit to Ex Post Cost Ratio for ESI Policies

	Ratio of Benefit : low ex Post cost		**Ratio of Benefit : high ex Post cost**	
	Where benefits = central low	Where benefits = central high	Where benefits = central low	Where benefits = central high
UNECE				
1st Sulphur Protocol	(>20)	(>20)	0.9	4.1
2nd Sulphur Protocol	(>20)	(>20)	(>20)	(>20)
IPC				
Low S Coal	(>20)	(>20)	(>20)	(>20)
FGD	1.6	7.5	1.6	7.5
Low NOx burners	2.4	15.1	2.4	15.1
Renewable Policy				
NFFO (all)	**0.6**	**2.6**	**0.6**	**2.6**

Note the costs and benefit of IPC measures are not additional to the UNECE protocol.

Benefits value excludes CO_2 benefits and benefits outside the UK.

3.6.5. An analysis of all the above information leads to the following conclusions:

- The benefits from achieving the emission reductions associated with the UNECE Sulphur Protocols are extremely large, especially when compared to the ex post out-turn. The benefit: cost ratio is extremely high for both the 1st and 2nd protocols when compared to the ex post costs, but in many cases the benefits are lower than the costs anticipated ex ante. It is stressed that the ex post out-turn was not so much due to an overestimation of the ex ante costs, but because the privatised sector met the target in a different (least cost) approach. It is stressed that these values only include UK benefits – one of the main drivers for the protocol was trans-boundary pollution. They also exclude ecosystem benefits. We therefore expect that the actual benefits are very much higher than shown. However, it can also be argued that the benefits over emphasise the importance of the UNECE protocols, as 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[68]. Care must also be taken not to double count the benefits of the UNECE target and IPC and the dash for gas[69].

- Integrated Pollution Control has led to the introduction of a number of technical measures and techniques, which have reduced emissions, and have led to large benefits. The measures include FGD, low sulphur coal, low NO_X burners, and particulate control. The ex ante costs predicted for all of these measures were significant. However, there is evidence to suggest that these were over-estimates, as shown in later cost assessments and ex post analysis. Interestingly, for most measures, there was a positive ratio of benefits to costs when benefits are compared to earlier ex ante studies. These ratios are much higher when benefits are compared to the later studies (mostly ex post studies). We do highlight, however, that FGD costs may actually rise in future years, relative to benefits, because of the lower load factors in use in coal plant.
- The absolute benefits of renewable policy are low because of the low contribution to the generation mix in the evaluation period (to 2001). Ex ante cost data is not available on renewable policy – only ex post out-turns. The overall comparison of NFFO for the evaluation period shows much that the estimate of ex post costs lies between the low and high estimate of benefits. We have also assessed the benefit to cost ratio for individual NFFO rounds. The summary information, showing the subsidy levels (as the difference between the spot price and the NFFO bid price) against the environmental costs avoided are presented in the figure below. For this graph we have also included the social cost of carbon values (using the illustrative central value only). It indicates that for early NFFO rounds (1 and 2) the benefits were less than the costs (unless a high value for the SCC is used), but for later rounds (3, 4 and 5), the benefits exceed costs. Interesting, the analysis also shows that projecting forward to 2010, it is difficult to justify the buy-out price for the renewables obligation on the basis of the future environmental costs for the generation mix. This is an interesting conclusion, though, it must be remembered that renewable policy had/has a broader remit than just environmental benefits.

[68] It is also interesting to ask 1) whether the UK would have gone ahead with environmental policies (especially the UNECE S protocols) if other drivers (liberalisation) had not occurred; 2) whether the 'dash for gas' would have occurred in the absence of environmental policies, such as the LCPD and the UNECE protocols, and 3) what would be the out-turn with liberalisation and IPC but without the UNECE protocoals? For 1), in the absence of other policies, it might be expected that electricity generation costs, and prices to consumers, would have risen. However, it is likely that there would have still been considerable pressure for the UK to proceed with sulphur abatement policies, i.e. even if this meant higher costs: such a position would have been similar to that facing other European countries at the same time. For 2) while there would have been an increase in gas use in the absence of environmental policy, there was also a driver from the constraints on new plants imposed by environmental legislation, which drove the rapid increase in the UK. For 3) if could be argued that the UNECE S protocols were not a necessary driver but did provide insurance against the failure of other mechanisms (liberalisation and IPC) to deliver.

[69] The combination of liberalisation and IPC has led to the UK overshooting the UNECE target, though the study here has shown that there has been a very large economic benefit from doing so.

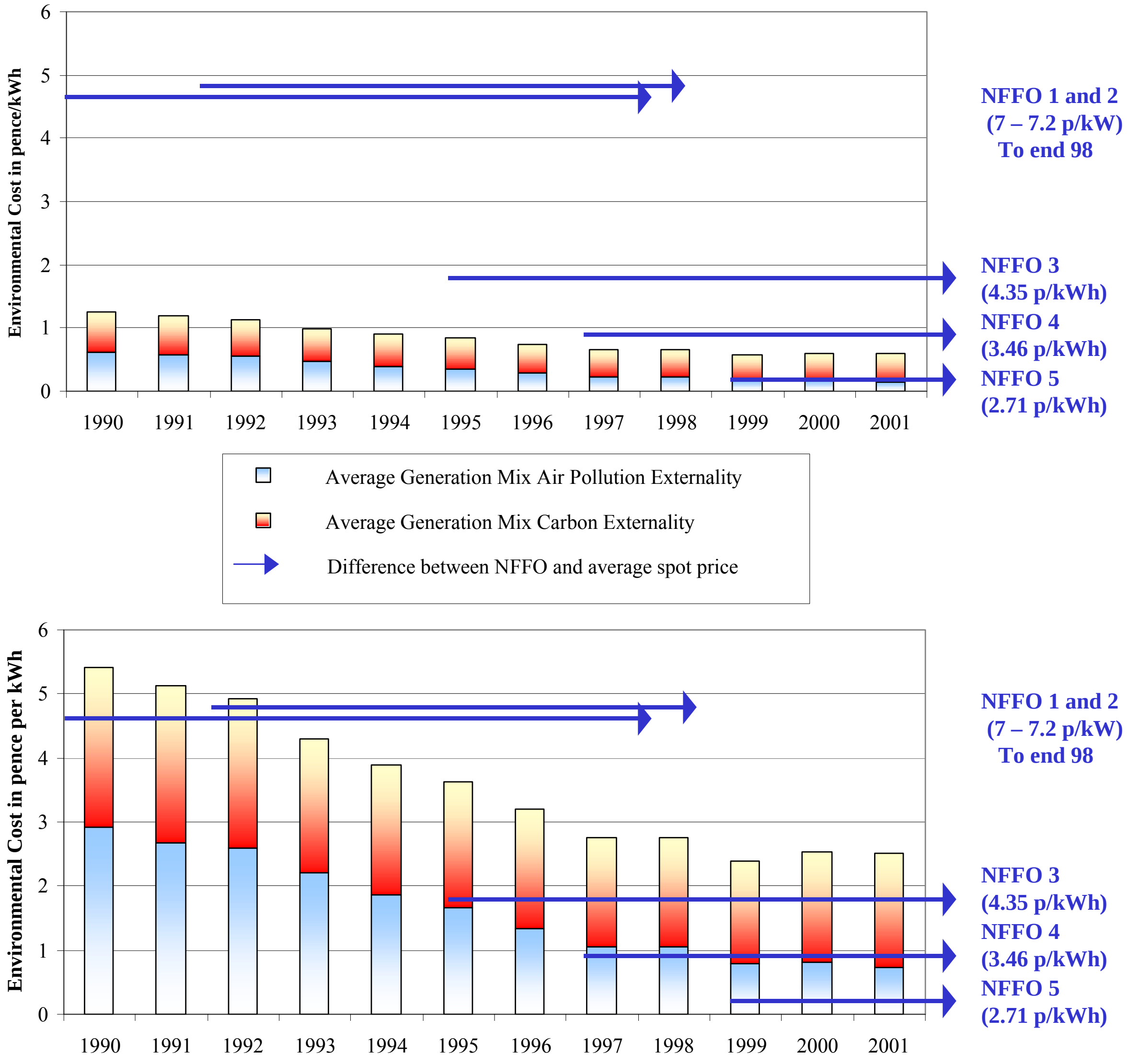

Figure 3-31. Comparison of Average Generation Mix Environment Costs vs. NFFO Subsidy Top Central Low. Bottom Central High.

Note the technologies in NFFO that have been most successful have been wind energy, landfill gas and waste to energy. Wind energy has almost zero environmental costs (~ 0.1 p/kWh). Waste to energy (and biomass) projects do not, because they emit regulated pollutants (NO_X and PM_{10})). The use of the average generation mix environmental costs above may therefore be a slight overestimate of the environmental benefits of renewables.

When comparing average price of NFFO rounds over and above average electricity price to the average generating mix environmental externality when the NFFO round commenced. Note in practice, the analysis should compare to the average generating mix over the lifetime that the renewable plant is operational (but data are note available for this calculation). This may slightly overestimate benefits of each NFFO round.

Note the numbers above do not include benefits from impacts not valued (particularly ecosystems). They only include UK benefits, and do not account for the benefits from the reduction in trans-boundary pollution. They do not include the effects of NO_X emissions on ozone formation.

Note the values assume the central illustrative SCC values (£70/tC). The range of values (£35 to £140/tC would significantly change the above analysis. We highlight that the value for the marginal social cost of carbon (for CO_2) includes effects in the UK and internationally, i.e. in contrast to the air quality analysis above. If the analysis of the marginal social cost of carbon in the UK only was used, this would produce a very much smaller value (almost negligible in fact) since the impact on the UK from changes in the UK's own emissions is practically zero.

3.6.6. It is highlighted that even for the analysis of benefits presented, certain categories of benefits (e.g. ecosystems) are excluded. These would alter the cost-benefit ratios seen –

especially for policies affecting SO_2 emissions – and would increase benefits. The inclusion of trans-boundary effects would also increase benefits. As with the analysis of the transport sector, there is a general trend that benefits are less than ex ante costs, but higher than ex post cost out-turns. Similarly, we find that secondary pollution (secondary particulates especially sulphates) must be quantified and valued in order for the benefit to cost ratios to become positive for most policies.

3.7 Conclusions and lessons for future policy

3.7.1. The policies implemented over the last decade in the ESI have had a major impact in improving air quality. The total emission reductions achieved, from all energy and environmental policies, have led to emission reductions in the evaluation period that are forecast to be 58% of NO_X emissions and 77% of SO_2 and PM_{10} emissions of the expected out-turn that would have occurred in the absence of these policies. These emission reductions are expected to increase through to 2010. The contribution of air quality policy to these emissions reductions depends on the assumptions made on the inter-actions between energy and air quality policy, but we estimate around 38 to 100 % of the SO_2 emissions achieved, 34 to 100% of the NO_X emissions reductions, and 46 to 100% of the PM_{10} emissions reductions seen can be attributed to air pollution policy.

3.7.2. Related to this, however, is the conclusion 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.

3.7.3. The emissions reductions have led to very large reductions in the potential health and non-health impacts of air pollution in the UK, as assessed by an ex post benefits analysis. It is stressed that the values are driven by the reduction in air pollution concentrations of sulphates (PM_{10}). These benefits are much larger than anticipated in the original policy appraisals, though there remain a number of important areas that have been omitted from quantification (notably ecosystem damage).

3.7.4. The upper estimates of the costs anticipated in appraisals, for most ESI policies, are higher than the ex post benefits (certainly for our low estimate of benefits). However, the benefits exceed the actual ex post costs. There is therefore an extremely strong ex post justification for these policies, when their 'value for money' is assessed using a cost-benefit analysis[70]

3.7.5. The analysis of individual ex ante and ex post technology costs shows that in most cases ex ante costs were over-estimates. However, we also highlight an important case where this is not the case, in relation to the costs of abatement equipment for current coal plant (e.g. in relation to the NECD and FGD), where costs are likely to be higher than originally anticipated, as other factors have led to these plants being used at lower load factors. In

[70] Note we highlight that the study has focused on the major policy initiatives in this sector and we have not considered all measures introduced such as some Government programmes (such as wider marketing or information programmes). No inferences should be drawn from the study about the relative effectiveness of instruments or policies beyond those explicitly covered in the study, or the potential application of similar policies to those considered here for other sectors.

general, the anticipated costs in appraisal have been less because lower cost approaches were found for meeting the objectives (e.g. gas use, low S coal).

3.7.6. Despite the undoubted success of the actions in improving air quality in the ESI a key factor must be considered. The nature of these measures (i.e. liberalisation) means that they cannot be repeated within the UK with similar effect. There is also the potential for a reversal of the trends back towards greater coal uses, should e.g. gas supplies become more expensive. This has already started to happen (with increases in coal use in 2000 and 2001).

3.7.7. The study has also considered lessons for future air quality policy. The analysis has shown that the reductions in primary PM_{10} emissions in the ESI have lower health benefits of than reductions in the transport sector. Indeed, the analysis here shows that the marginal benefit per tonne of primary PM_{10} abated in the transport sector has 50 times the health benefit of primary PM_{10} from the ESI. The reason for this is that tall stack emissions of PM_{10} from electricity plants lead to much lower population weighted exposures than ground level emissions in urban areas from transport. This conclusion has major policy relevance. We conclude that further action to reduce primary PM_{10} is likely (though not guaranteed) to be much more cost-effective for the transport sector, rather than the ESI, when the overall costs and benefits of policy options are assessed. However, it is also necessary to consider the role of secondary particulates and PM_{10}.

3.7.8. The study has also shown that the reductions in SO_2 from the ESI have led to extremely large reductions in PM_{10} concentrations even though this was not the primary policy aim (the primary aim being SO_2 reductions). Indeed, the benefits of SO_2 reductions for the ESI are larger than those from all transport policies considered. This leads to an interesting conclusion – from the current position, future policies in the ESI might achieve greatest health improvement by reducing SO_2 emissions in order to reduce secondary PM_{10} (provided the health evidence for sulphates as a causal pollutant remains). In effect, the marginal benefit per tonne of pollutant abated may be greater for SO_2 emissions as secondary PM_{10} than it is for primary ESI PM_{10}. It would be possible to combine the marginal benefits identified here with remaining options for reducing different pollutants (e.g. SO_2 and PM_{10}) in the ESI to confirm these conclusions. This is identified as a research priority.

3.7.9. The benefits of reducing NO_X, in terms of the potential secondary particulate benefits (nitrates) have been found to be very similar, per tonne of pollutant emitted, in the ESI and the transport sectors. A different conclusion, however, is reached for NO_2, where the ESI has much lower benefits in reducing population weighted exposure 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, given benefits are dominated by secondary species, it may be that further action to reduce NO_X from the ESI is effective in terms of actual health benefits.

3.7.10. 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. This leads to the final issue raised for future air quality policy. At the start of the 1990s, the environmental costs of electricity generation were dominated by air pollution. By 2010, although total air pollution costs will still be high, the air pollution costs per kWh 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.