Economic Evaluation of Air Quality Targets for CO and Benzene

A report produced for European Commission DGXI

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Executive Summary

This report presents work undertaken for the DGXI study on 'Economic Evaluation of Air Quality Targets for Carbon Monoxide (CO) and Benzene'. The objective of the study was to identify and estimate the costs and benefits of meeting ambient air quality standards for CO and benzene. The analysis specifically accounts for areas of peak concentration ('hot-spots') as well as areas where 'urban background' conditions apply.

A number of difficulties were encountered during the course of this work, which should be regarded as priorities for further data collection and research activities. First there is inconsistency in inventories between different countries. Second, the cost-benefit assessment was made extremely difficult by the lack of good exposure-response data for both of the pollutants considered. A third difficulty concerned the overall framework for this analysis. From the perspective of cost-effectiveness it would be preferable in future analysis of air quality limits to take a broader approach, considering a much larger number of pollutants (e.g. SO_2, NO_2, PM, lead, CO, benzene, O_3) simultaneously. This would allow better integration of the secondary effects of abatement of individual pollutants, for example through reductions in emissions of the other pollutants being considered. Overall this should lead to a more optimal selection of abatement technologies.

Analysis concentrated on three cities, Athens, Cologne and London. Results from these cities were extrapolated to the rest of the European Union. The Steering Group for this work requested that the following values be investigated as possible limits in this study.

- For benzene: 2, 5 and 10 ug/m^3 as annual average to be attained by 2010.
- For CO: 10 mg/m^3 maximum 8 hour mean concentration, and 10 mg/m^3 second highest 8 hour mean concentration to be attained by 2005.

These limits were to be investigated for both urban background and hot-spot locations.

The methodology for this study follows to a large extent extrapolation of the results of the first Auto-Oil Programme (AOP I). AOP I provided detailed modelled assessments of urban background air quality across 7 cities, these cities being broadly representative with respect to air quality of all cities in the European Union. It also provided a set of data and assumptions that have already been widely reviewed, discussed and agreed by European decision makers and other interested parties.

The baseline scenario used here incorporated the Auto-Oil Directives on fuel quality and vehicle emissions and the first daughter Directive on SO_2, PM, NO_2 and lead, using results from an earlier study conducted for the Commission. There is emerging evidence that the measures considered in that earlier study would not be sufficient to meet the limits contained in the first daughter Directive. Given the commonality of sources for the pollutants considered, and the particular effect of transport in areas where exceedences are most likely it is possible that this will mean that the present analysis overestimates future benzene and CO levels.

Aggregated results for CO are shown in Table 1, and for benzene in Table 2. A number of uncertainties have been explored in these tables. For CO the following are considered:

- Low (L), medium (M) and high (H) emission scenarios, accounting for possible variation in traffic growth and the penetration of advanced technologies.
- Relationship between urban background and hot-spot concentrations, for which the 'core' prediction represents the best estimate, and the 'upper' estimate is based on extreme meteorology.
- Inclusion/exclusion of the possible acute effects of CO on mortality (the column headed 'benefits (sensitivity)' includes effects on mortality and the prevalence of Congestive heart failure (CHF), whilst the column headed 'benefits' includes CHF alone).

Table 1. Aggregated results for CO, including sensitivity analyses. (Million Euro).

Limit	Location	Emission Scenario	Case	Benefits	Benefits (sensitivity)	Costs
All	urban back	All	-	No exceedance		
10 mg/m^3 2nd highest	hot-spot	L	Core	0	0	0
		M	Core	0	0	0
		H	Core	3.2	15	65
10 mg/m^3 2nd highest	hot-spot	L	Upper	0	0	0
		M	Upper	0.048	0.23	0.15
		H	Upper	11	37	270
10 mg/m^3 highest	hot-spot	L	Core	0	0	0
		M	Core	0.026	0.12	0.058
		H	Core	6.4	30	200
10 mg/m^3 highest	hot-spot	L	Upper	0.026	0.12	0.018
		M	Upper	1.4	6.4	19
		H	Upper	22	100	550

Whilst for benzene the following sensitivities were explored:

- Emission scenarios (low, medium, high, as discussed above for CO)
- Relationship between urban background and hot-spot concentrations
- The risk factor determining the number of cancers likely to be linked to a given level of benzene
- Whether measures are strongly targeted (optimised abatement case) or weakly targeted (generalised abatement case) at the locations where exceedences occur.

Table 2. Aggregated results of the analysis for benzene, estimating costs and benefits throughout the EU per annum. Cells with '0' entered represent cases where no exceedence is predicted.

Limit			Impacts (cases)		Benefits (kEuro)		Costs (kEuro)
μg/m^3	Location	Emissions	Low	High	Low	High	
2	urban back	L – opt	0.0003	0.034	0.67	119	890
		M – opt	0.0059	0.59	12	2,107	71,800
		H – opt	0.010	1.0	20	3,583	207,850
2	hot spot	L – gen	0.081	8.1	162	14,344	9,774,150
		M – gen	0.13	13	265	23,151	23,059,710
		H – gen	0.16	16	330	28,691	34,491,730
2	hot spot	L – opt	0.037	3.7	74	6,879	976,220
		M – opt	0.077	7.7	153	12,463	3,539,690
		H – opt	0.13	13	263	20,713	8,389,050
5	urban back	L – opt	0	0	0	0	0
		M – opt	0	0	0	0	0
		H – opt	0	0	0	0	0
5	hot spot	L – opt	0.0030	0.30	5.9	1,058	24,330
		M – opt	0.010	1.0	20	3,511	226,360
		H – opt	0.019	1.9	37	5,619	465,280
10	urban back	L – opt	0	0	0	0	0
		M – opt	0	0	0	0	0
		H – opt	0	0	0	0	0
10	hot spot	L – opt	0	0	0	0	0
		M – opt	0	0	0	0	0
		H – opt	0.0040	0.40	7.9	1,404	45,590

There is a tendency for costs to significantly exceed benefits where exceedences are likely to occur. There are several points that should be noted here however:

1. In many cases it is likely that concentrations estimated here are overestimated. Further abatement to that considered here in our baseline scenario may well follow without further action to control CO and benzene. This may arise through measures needed to control other air pollutants, congestion, and other impacts of transport. A further factor is the potential introduction of new technologies, which could make an impact on benzene levels by 2010. This would lower both the costs and benefits of achieving the limit values.
2. Secondary effects of abating CO and benzene, for example on ozone levels, were not considered. The logic for including such effects (see Table 3) within the context of the Framework Directive is unclear.

Table 3. Secondary effects of the abatement of CO and benzene.

Abatement measure	Burden affected	Impacts affected
Traffic calming, public transport subsidies, etc.	Emission of all transport pollutants (SO_2, NO_x, PM_{10}, VOCs, CO_2 etc.. generation of related secondary pollutants such as ozone)	Effects on health, materials, ecology
	Risk of accidents	Death and injury, material damage
	Congestion	Travel time
	Noise	Amenity
Emission constraints	Emission of all transport pollutants (SO_2, NO_x, PM_{10}, VOCs, CO_2 etc.)	Effects on health, materials, ecology

3. In many cases the extent of exceedence was tightly constrained, geographically and with respect to the amount of exceedence. This makes it more likely that the issues raised at [1] could lead to certain limits being met without controls being directed specifically at CO or benzene. The clear exception to this was the limit of 2 $\mu g/m^3$ for benzene applied in hot-spots.

Analysis of CO effects based on available epidemiological data is subject to much uncertainty, given the limited amount of data that exist. Three exposure response functions have been reported in the literature, for acute (short term) effects on mortality, ischaemic heart disease (disease associated with a lack of blood supply to the heart) and congestive heart failure (CHF). Of these only the last appears reasonably robust, once account has been taken of other pollutants. However, the logic of including one type of heart disease but not another for which there appears reasonable grounds for believing that there should be an association with CO may be questionable. Equally, including heart disease, but not premature mortality may also be questionable. The effect of CO exposure from ambient air may just be to bring the date of hospitalisation or death forward by a limited time: the primary cause of heart disease or the timing of death may lie elsewhere (e.g. smoking, diet, lack of exercise, etc.). The epidemiology unfortunately does not provide answers to these questions. Available ‘response profiles’ showing the effects linked to different concentrations of carboxyhaemoglobin (COHb) in blood are reasonably well accepted but are not amenable to application in this type of analysis. Estimated impacts and associated costs given for CO in this report should thus be regarded as very uncertain, with this uncertainty reflecting the limited attention that has so far been given to CO in epidemiological studies.

Problems also exist in the quantification of benzene risks, with a factor 100 difference between the high and low estimates of risk. Further research on the mechanism of benzene effects may reduce this uncertainty in the near future.

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Appendices

1 Introduction

1.1 EUROPEAN LEGISLATION ON AIR QUALITY

The objectives of the Framework Directive on Air Quality (Council Directive 96/62/EC of 27 September 1996 on ambient air quality assessment and management) are to:

- define and establish objectives for ambient air quality designed to avoid, prevent or reduce harmful effects on human health and the environment as a whole;
- assess the ambient air quality in Member States on the basis of common methods and criteria;
- obtain adequate information on ambient air quality and ensure that it is made available to the public as necessary;
- maintain ambient air quality where it is good and improve it in other cases.

Under this Directive so far, work on SO_2, NO_x, fine particles and lead has been completed. This study forms part of a second phase, and investigates possible standards for carbon monoxide (CO) and benzene. Work on limits for ozone is near completion. It should be noted that any action on any one of these pollutants is likely to affect the concentration of the other pollutants. In particular, action to reduce levels of PM_{10} and NO_x is likely to affect emissions of CO and benzene also, because transport tends to be the dominant source for all four pollutants in areas where exceedences occur.

The Framework Directive defines the rationale for:

- selecting pollutants for consideration in the subsequent daughter directives;
- setting limit values, target values and alert thresholds;
- defining the time frame for derivation of values;
- quantifying the number of sampling points needed, and criteria related to the siting of monitors;
- selecting methods for measuring and estimating pollutant levels.

The Directive notes a number of factors which may be taken into account when setting limit values and alert thresholds, though the list is indicative, rather than exhaustive. Those factors listed of most relevance here are:

- degree of exposure of sectors of the population, and in particular sensitive sub-groups;
- climatic conditions;
- economic and technical feasibility of attaining targets;
- long-range transmission of pollutants, including secondary pollutants such as ozone.

No definition or example is provided in the Directive for what constitutes a ‘sensitive sub-group’. However, two groups of people can be identified as potentially more sensitive than the general population. The first is sensitive on medical grounds. This includes (though is not necessarily restricted to) people with pre-existing symptoms, such as circulatory problems, small children whose immune systems may not be fully developed and people who have heightened sensitivity because of genetic factors. The second group owes its heightened sensitivity to excess exposure to the pollutants of interest. This includes people living in areas where pollutant levels are locally high (e.g. adjacent to petrol stations, some industrial sites, and busy roads). It also includes people exposed in the workplace (e.g. refineries, petrol stations, other industrial sites, car parks, tunnel-workers), and smokers (smoking being a major source of exposure for both CO and benzene).

The fact that there is a significant level of exposure in the workplace and through smoking creates an important issue in the development of legislation. Legislation controlling outdoor air pollution will have relatively little effect on the exposure of these subgroups. Therefore it is logical that the analysis should consider the incremental risk associated with ambient air exposures faced by members of the population, rather than the absolute risk that they face from exposures to all sources.

Particular interest has focused on benzene, as it is the first carcinogen to be considered under the EU's Framework Directive. In comparison, CO in the ambient air has attracted relatively little attention, though it has a well-established link with health and has recently been associated with significant effects on health in some epidemiological studies. The outcome of these studies is mixed, however; some find a significant link between CO and health, some don't, and some others initially identify a significant association only for it to disappear once other pollutants such as PM_{10} are brought into the analysis. Fatal CO poisonings as often reported in the press are not relevant to this study, as they do not reflect exposure to the ambient air. They are typically associated with exposure to fumes from defective or poorly vented domestic gas appliances in the case of accidental deaths, or to car exhaust fumes, in the case of suicides.

1.2 REMIT OF THIS STUDY

1.2.1 Objectives

The objective of the study is to identify and estimate the costs and benefits of meeting ambient air quality standards for CO and benzene. The specific tasks in the project are to:

1. Determine areas of excess pollution according to pre-specified limit values, taking into account the (future) impact of current and planned (Commission agreed) legislation.
2. Identify regions and sectors responsible for excess air pollution.
3. Provide an overview of possible measures and associated costs in the relevant regions to meet the limit values.
4. Determine a least-cost package of measures to meet the ambient targets.
5. Assess the benefits of implementing such measures.
6. Compare costs and benefits and conduct sensitivity analysis.

1.2.2 Relationship to other activities

This study was carried out to inform the EC DGXI Working Group on Benzene, and the EC DGXI Invited Experts Group on CO, regarding economic issues linked to the development of air quality limit values for the two pollutants.

The work is also strongly linked to the Auto-Oil Programme, as vehicles are the main sources of CO and benzene in the outdoor air. In the first phase of this programme, which was known as Auto-Oil I (hereafter referred to as AOP I) both benzene and CO were specifically considered. Three main reports were produced under AOP I:

- Air quality modelling (European Commission DGXI, 1996);
- Emissions, fuels and engine technologies (ACEA/europia, undated);
- Cost Effectiveness (Touche-Ross, 1995).

In due course it should be worthwhile comparing the findings of this study with those that will be generated by the second phase of the Auto-Oil Programme (AOP II). No results were available from AOP II during this study.

1.3 OVERVIEW OF THE ANALYSIS

In essence the study has four main activities:

1. Determination of areas of 'excess' pollution;
2. Cost-effectiveness analysis, i.e. consideration of the potential for reducing concentrations of CO and benzene and the costs of doing so;
3. The benefit analysis, determining the monetary value of environmental improvements achieved by alternative strategies;
4. Comparison of the costs of strategies with monetised environmental benefits, including exploration of the effects of uncertainties (particularly those affecting benefits estimates) on net costs/benefits.
5. Sensitivity analysis.

In the first instance these activities are carried as case studies on a small number of cities (one city in each of the UK, Germany and Greece). Following that the results are scaled up to the level of the EU.

1.4 STRUCTURE OF THIS REPORT

The report is structured as follows. Chapters 2 to 4 summarise most of the raw data used in the study, and Chapter 5 describes how these data are brought together for the analysis. More precisely, Chapter 2 provides details of the scenarios that are being considered and the main sources of emissions for the two pollutants. Chapter 3 discusses the effects linked to reduction of emissions of carbon monoxide and benzene respectively, including indirect effects, and describes the rationale followed here for including and excluding specific effects from the analysis. Chapter 4 reviews information on the technical and non-technical measures available for reduction of CO and benzene emissions from the transport sector: the dominant source of urban exposure to both pollutants in the ambient air.

Results for case studies considering the situation in Athens, Cologne and London, and the extrapolation of these results to the level of the EU are given in Chapters 6 and 7 for CO and benzene respectively, followed by conclusions for the study.

Background data are given in a series of appendices:

- Appendix I: Factors for converting CO and benzene measures
- Appendix II: A brief glossary of medical terms used in the report.
- Appendix III: Review of data used for converting between urban background and hot spot concentrations in urban areas.
- Appendix IV: Listing of legislation considered to be in force in the baseline scenario.
- Appendix V: Review of data on reducing emissions of benzene from stationary sources.

2 Scenarios and Emission Sources

2.1 INTRODUCTION

Two baseline scenarios have been defined. The first considers the finalised Auto Oil Directives on fuel quality and emissions from motor vehicles[1]. The second integrates the findings of the economic evaluation for air quality limits for SO_2, NO_x PM_{10} and lead (IVM, 1997). The Solvents Directive (COM(96) 538) seems unlikely to have a significant effect on benzene levels specifically and hence its effects have not been considered.

Inevitably other actions in the future will influence the concentrations of CO and benzene. A particular example at the present time concerns the effect of the Kyoto summit on climate change. Given that the main source of both benzene and CO in the ambient air is fossil fuel use, much of which is from the transport sector, any measures to reduce CO_2 emissions from transport would seem likely to affect emissions of CO and benzene as well. Consideration of additional measures for greenhouse gas emission reduction was not made for this study because the required legislation has not progressed far enough for integration in this study with any confidence. There is also good evidence now that the IVM analysis was too conservative in its predictions of PM_{10} and NO_x levels and that additional measures will need to be taken to ensure compliance with limit values for those pollutants. This too will affect levels of CO and benzene. Another example concerns measures to abate VOC emissions (including of course benzene, amongst many other species of VOC) to reduce tropospheric ozone concentrations. The effect of inclusion of these measures is described only qualitatively in this report.

AOP I provides a good starting point for our analysis. It was widely discussed across Europe and hence a large number of people are aware of the advantages and limitations of that work. It also addressed both CO and benzene specifically. It was predicted that there would only be exceedence of limit values for benzene and CO if the standards to be adopted for air quality were, in the words of the authors "very severe". However, an important caveat was added to this, for all pollutants (European Commission DGXI, 1996, page 135), recognising that the AOP I conclusions strictly applied only to urban background locations. It was then stated that:

> *'If future European air quality standards are to be met at roadside locations, further reductions than those predicted* [in Auto Oil] *may be required.'*

In various discussions of the standards for ambient air quality in working groups, the steering group and the European Commission it was agreed that the standards should be met at roadside locations. The findings from AOP I are therefore of limited importance

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[1] The previous draft reports under this contract were written before the final position on these directives was agreed. Incorporation of the final decision on these Directives has made a significant difference to the results of the cost-benefit assessment in some countries.

here. However, they remain useful and so further details are shown in Tables 2.1 and 2.2 (European Commission DGXI, 1996). The necessary reductions in emissions in both Madrid and Milan were assumed to be zero, following comparison with the analysis conducted in the other five cities.

Table 2.1. Emission reduction targets for CO under AOP I. All figures are given as annual mean concentrations. The 3 mg/m^3 limit corresponds to an 8 hour limit of 10 mg/m^3 as 98th percentile (i.e. exceeded for only 2% of the year). The 1.5 mg/m^3 limit corresponds to an 8 hour limit of 10 mg/m^3 with no exceedences.

City	1990 annual mean mg/m^3	2010 max level mg/m^3	Emissions reduction for upper target level (3 mg/m^3) in 2010	Emissions reduction for lower target level (1.5 mg/m^3) in 2010
Athens	4.1	0.85	0	0
Koln	1.1	0.46	0	0
London	1.2	0.75	0	0
Lyon	4.6	0.72	0	0
Madrid	2.2	not estimated	assumed 0	assumed 0
Milan	3.4	not estimated	assumed 0	assumed 0
The Hague	not measured	0.42	0	0

Table 2.2. Emission reduction targets of benzene under AOP I. All limits as annual means.

City	2010 max level µg /m^3	Emissions reduction for upper target level (16 µg/m^3) in 2010	Emissions reduction for lower target level (10 µg/m^3) in 2010	Emissions reduction to meet target value of 2.5 µg/m^3 in 2010
Athens	5.7	0	0	55%
Koln	2.8	0	0	10%
London	3.8	0	0	35%
Lyon	4.4	0	0	45%
Madrid	4.8	0	0	50%
Milan	3.2	0	0	20%
The Hague	2.3	0	0	0%

2.2 SOURCES OF CO AND BENZENE

The main source of benzene within the European Union is traffic, as shown in Table 2.3 which brings together information from five countries submitted to the Working Group on Benzene (IIA, 1998). There is a lack of consistency in the classification between different countries. A clearer picture can be given (Table 2.4) by adding data into five different categories:

A: Transport
B: Energy industries
C: Non-energy industries
D: Domestic
E: Other

Table 2.3. Percentage emissions of benzene from different sources in Italy, Sweden, Germany, the Netherlands and the UK.

		Italy	**Swe**	**Ger**	**Neth**	**UK**	**Europe**
Total benzene (ktonnes/year)		23.8	23	43	8	35	?
Year		1995	1994	1994	1995	1995	?
Source							
A	Vehicular traffic	76.9		93	50		80-85
A	Road traffic including petrol evap. + asphalting		38				
A	Petrol engines					65.3	
A	Diesel engines					1.3	
A	Other mobiles sources		3			7.7	
A	Vehicle evaporation	12.1				5.8	
A	Evaporative emissions	2.6					
B	Petroleum refineries						0.3-1.5
B	Energy production		<1				
B	Fuel distribution						2.6-6.0
B	Stationary combustion					6.9	
B	Gas leakage						
B	Power generation				23		
B	Prod/distribution evap.	2.9				3.7	
B	Small scale wood combustion		54				
C	Industry		3	5	8	8.3	
C	Chemical industry						1.3-13
C	Working machinery		4				
C	Solvent use					0.7	1-4
C	Pesticides		<1				
C	Combustion of oil etc.						
C	Other industry						
D	Domestic use		<1	2			3-7
D	Domestic/small installations				13		
E	Other	5.5			6	0.5	

Table 2.4. Collated data on percentage of emissions of benzene from different sources for the 5 countries shown in Table 2.3.

		Italy	**Swe**	**Ger**	**Neth**	**UK**	**Europe**
A	Transport	91.6	38	93	50	79.5	80-85
B	Energy industries	2.9	54	5	31	10.6	2.9-7.5
C	Other industry	5.5	7			9	2.3-17
D	Domestic		<1	2	13	-	3-7

E	Other	-	-	6	0.5	-

Note: Data excludes benzene from natural sources (est. 3-5% of total).

Results for Italy, Germany and the UK appear to be consistent. Data for Sweden and the Netherlands are not, with high proportions of emissions arising from small scale wood combustion and power generation respectively. These data suggest that further action is needed to ensure consistency between emission inventories in different countries. Unless the inventories are comprehensive there is a risk that policies identified for emissions abatement could be far from optimal. It must be added that in the present case this seems unlikely, as there is good consensus that the problems of CO and benzene are mainly traffic related.

Data for CO are shown in Table 2.5, drawing on CORINAIR (1997). The highest emissions are associated with road transport and ‘combustion’.

Table 2.5. Emissions of CO in the EU in 1994. All figures given as percentages except the totals for the EU, which are expressed in 1000 tonnes. (Source: CORINAIR, 1997).

	Combustion	Production processes	Road transport	Other mobile	Waste	Other
Austria	43%	25%	31%	1%	0%	0%
Belgium	11%	1%	85%	0%	2%	0%
Denmark	26%	0%	58%	11%	0%	7%
Finland	20%	0%	71%	9%	0%	0%
France	25%	6%	54%	10%	2%	20%
Germany	29%	9%	58%	4%	0%	2%
Greece	2%	2%	82%	3%	0%	25%
Ireland	20%	0%	78%	2%	0%	0%
Italy	8%	5%	63%	7%	17%	6%
Luxembourg	58%	10%	30%	2%	0%	0%
Netherlands	25%	12%	56%	3%	0%	7%
Portugal	36%	1%	61%	1%	0%	0%
Spain	27%	5%	57%	2%	7%	24%
Sweden	2%	0%	89%	8%	0%	0%
UK	9%	0%	88%	1%	1%	9%
EU %	20%	6%	63%	5%	5%	1%
EU 1000 t	8636	2423	27839	2418	2156	543

For both CO and benzene the source of most concern is road transport, and hence this is the source that the present report is focused on.

2.3 SCENARIOS

The main analysis presented in this study concentrates on the effects of vehicle emissions, given that they are the dominant source of the pollutants of interest here. The baseline scenario for the analysis considers all legislation on vehicle emissions and fuel quality up to the final position on Auto Oil, in which previously indicative standards for 2005 were made mandatory. The legislation is listed in Appendix 4. For Athens alone this was updated to take account of introducing the daughter Directive on NO_2, PM_{10}, SO_2 and lead. Athens was the only one of the three cities considered in the case studies presented in this report for which an earlier consultants report (IVM, 1997) concluded that exceedences would be observed under the first daughter Directive. The measures identified by IVM (road pricing and the use of buses powered by compressed natural gas - CNG) were thus applied to Athens, but not to Cologne or London.

2.4 CONSEQUENCES OF A NEED FOR MORE STRINGENT ACTION ON NO_2 AND PM_{10} THAN FORESEEN BY IVM (1997)

Analysis in the UK suggests that exceedences of NO_2 and PM_{10} could be more widespread than the IVM report indicated, if specific account were taken of levels at kerbside (Johnson *et al*, 1997). This would appear to apply elsewhere in the European Union also. The measures that would need to be introduced would include those identified by IVM, and others that would also impact on CO and benzene concentrations. A list of possible measures was provided by the European Commission's Working Group on NO_2 (European Commission Working Group on NO_2, 1997), and is reproduced here as Table 2.6. Most of the measures listed would influence CO and benzene emissions also.

Table 2.6. Actions for reduction of NO_2 concentrations in air (European Commission Working Group on NO_2, 1997).

EU Level	National Level	Local Level
Vehicle emission reduction	Emission standards	Local vehicle restrictions
Vehicle inspection	Environmental permit	Alternative fuels
Energy conservation	Energy conservation	Energy conservation
Point source emission reductions		
Fuel standards		
Air quality standards	Transport infra-structure	Alternative transport systems
Fiscal incentives	Fiscal incentives	Road and parking pricing
Sustainable city planning	Informatic highways	Traffic planning, management
Behaviour, education, awareness	Behaviour, education, awareness	Behaviour, education, awareness
Traffic planning	Traffic planning	Transport system planning
Scrapping subsidies		Traffic information
		Environmental zoning
Research	Research	

It would be expected that general measures to reduce vehicle emissions will cause a greater percentage reduction in concentrations of CO and benzene than of NO_2 or PM_{10}. This is because of the larger contribution of stationary sources to concentrations of NO_2 and non-transport sources generally (including natural particulates) for PM_{10}. The effect of error in quantifying necessary abatement for the first daughter Directive could thus be significant for the analysis presented here.

2.5 LIMIT VALUES ASSESSED IN THIS STUDY

The Steering Group on Ambient Air Quality convened by EC DGXI requested that two limit values be investigated for CO, and three for benzene. None of these values were to be regarded during the analysis as preferred to any other. It was also said that the analysis should take specific account of both urban background and 'hot-spot' locations, particularly partially enclosed areas where emissions are high, such as the so-called 'canyon streets'. The analysis was not to extend to consideration of concentrations in some more enclosed areas such as road tunnels or car parks.

2.5.1 CO

WHO have recommended a number of possible limit levels over averaging periods ranging from 15 minutes to 8 hours:

100 mg/m^3 for 15 minutes
60 mg/m^3 for 30 minutes
30 mg/m^3 for 1 hour
10 mg/m^3 for 8 hours

In practice the 8 hour level is the most protective - available monitoring data suggest that the other guidelines are extremely unlikely to be exceeded if the 8 hour guideline is not exceeded (van den Hout, 1997). Van den Hout found that 26% of the data series in the APIS database for CO in the period 1989 to 1994 are above the WHO 8 hour limit.

As shown above, the results of the analysis carried out under AOP I show that for the 7 cities studied (Athens, Cologne, the Hague, London, Lyon, Madrid and Milan) there would not be exceedence of the 10 mg/m^3 8 hour guideline by urban background concentrations by the year 2005. The major factor in this is the increased penetration of cars fitted with three way catalytic converters, which is good enough to more than outweigh projected increases in vehicle usage. Given that the range of cities studied in AOP I were selected partly on the basis that they were representative of cities across the European Union (regarding air quality, size, location, topography, etc.), this implies that a 10 mg/m^3 8 hour standard will not be breached anywhere in the EU as an urban background level. AOP I did not, however, address the situation in hot-spots.

The limit values considered here for CO for 2005 were:

- 10 mg/m^3 as maximum 8 hour average
- 10 mg/m^3 as second highest 8 hour average in any year

The second, more relaxed limit value was included to account for the possibility of (e.g.) extreme weather conditions.

2.5.2 Benzene

WHO have made estimates of the average concentrations of benzene associated with a range of excess lifetime risk of leukaemia from airborne benzene, as follows (Table 2.7):

Table 2.7. Benzene exposure and excess lifetime risk of leukaemia (WHO, 1996).

Risk	Estimated concentration $\mu g/m^3$
1/10,000	17
1/100,000	1.7
1/1,000,000	0.17

From the Table the risk normalised per $\mu g/m^3$ can be calculated by dividing risk by the concentration associated with that level of risk. Based on the data given in the Table this gives a normalised risk of ([1/1,000,000]/0.17), equal to 5.88 cases per $\mu g/m^3$. The Working Group took a slightly lower estimate of 5 cases per $\mu g/m^3$ (see below).

The term excess lifetime risk refers to the probability that an individual would experience that risk (in this case develop cancer) within their lifetime as a consequence of exposure to the agent of concern, in this case benzene. The risk is 'excess' in the sense that it is additional to the underlying risk of developing cancer. Factors are divided by average life expectancy to obtain the annual excess incidence of cancer.

An ad hoc working group convened under the Working Group on Benzene further reviewed data on benzene risk. They thought that the WHO estimate erred towards being too conservative (i.e. an overestimate of risk), and preferred to cite a range for the exposure-response function. This range is extremely broad. Uncertainty arises because the population for which exposure-effect data are available experience a very different regime (relatively short duration to high exposures) to the general population (lifetime exposures to very low concentrations). The recommended range thus spans 2 orders of magnitude: 5.10^{-6} per $\mu g/m^3$ to 5.10^{-8} per $\mu g/m^3$. Although this range is broad the lack of data on benzene exposures at low concentrations does not permit it to be reduced, or inference to be drawn on the distribution of probabilities within the range. This source of uncertainty not surprisingly dominates estimates of the direct benefits of reducing benzene levels.

Under AOP I a standard of 2.5 $\mu g/m^3$ was regarded as being very severe from the perspective of achievement (European Commission DGXI, 1996). Nonetheless, because of benzene's role as a carcinogen, for which it is generally considered that there is no truly 'safe' level, a number of EU Member States have set very low limits, to be met in the long term. Accounting for the variation in perceived risk of harm from benzene, the steering group on air quality requested that this study consider limit values of 2, 5 and 10 $\mu g/m^3$.

3 Effects of Emissions of CO and Benzene, and Exposure Data

3.1 CARBON MONOXIDE

3.1.1 Effects of CO

Carbon monoxide is perhaps unique amongst the major air pollutants in having for many years a known mechanism of effect on human health: the formation of carboxyhaemoglobin (COHb) and associated reduction in the oxygen carrying capacity of the blood. Table 3.1 reviews the effects of increasing concentrations of COHb in the bloodstream.

Table 3.1. Effects of increasing levels of carboxyhaemoglobin (COHb) in the human body.

Effect	**COHb level (%)**	**Reference**
Decreased exercise duration in patients with angina	2.5-3.0	Aronow *et al* (1972), Aronow and Isbell (1973) and Anderson *et al* (1973)
Increased frequencies of arhythmias in patients with coronary disease	no effect at 3.5; effect at 5.0	Sheps *et al* (1987)
Low birth weight	Foetal level of 2-10 caused by maternal smoking	Longo *et al* (1977)
Reduced co-ordination, tracking and driving ability	5.1-8.2	ACGIH Chemical Substances TLV Committee (1991), Putz (1979) and Benignus *et al* (1987)
Reduced cognitive performance	5-20	Laties and Merigan (1979)
Throbbing Headache	20-30	EPAQS (1994)
Dizziness, nausea, weakness and collapse	30-50	EPAQS (1994)
Coma and death	50-60	US EPA (1991)

It is not possible to use the data in Table 3.1 for quantification of impacts and associated costs from exposure to ambient levels of CO, given a lack of data in three areas;

1. COHb concentrations in the general population
2. A lack of quantified exposure-response data for the effects listed
3. A lack of valuation data for some of the health effects listed.

Table 3.1 needs to be put into context against ambient concentrations of CO in European cities, to show what level of effect is likely from exposure to ambient sources of CO. Data presented in the EPAQS (1994a) review in the UK show that non-smokers engaging in a variety of activities in locations subject to different CO concentrations are unlikely to have COHb levels in excess of 2.5% (Table 3.2). Levels up to around 5% are possible among smokers. Exposure to CO at sufficiently high levels to lead to the high COHb concentrations associated with throbbing headache, dizziness, coma or death is linked to faulty domestic appliances, particularly un-vented water heaters, and suicide from deliberate inhalation of car exhaust fumes[2]. It is not associated with exposure in the open air. Much of the data used in Table 3.2 is old, dating from the 1960s. Given measures that have been introduced to limit CO emissions already it should be noted that under current conditions exposure to CO is less than that shown.

Table 3.2. COHb levels in the population under different exposure conditions (EPAQS, 1994a).

Exposure situation	COHb%	
	Non-smokers	Smokers
Calculated values		
Rural background exposure	0.5 [1]	-
Urban exposure to 10 ppm [2]	1.0	-
Urban exposure to 25 ppm [2]	2.7	-
Measured values [3]		
Urban background exposure	0.8	3.5
Point-duty police (after 3 hours in busy street)	1.9	3.6
Others on foot in busy streets	1.2	-
Cyclists (city streets)	1.7	-
Motorists	1.8	-
Staff in parking garages	2.4	5.0
Staff in customs sheds, ferries	1.3	4.2

Notes: 1) Represents background value due to the natural formation of CO in the body. 2) Values estimated on the assumption that individuals are taking light exercise whilst continuously exposed to the given concentration for 8 hours. 3) Adapted from Lawther and Commins (1970), from measurements taken in the late 1960s in groups of between 5 and 165 people. EPAQS comment that they expect levels of COHb to be lower now.

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[2] The adoption of three way catalytic converters has had a notable effect on reducing the success rate of such attempts at deliberate suicide.

3.1.2 Epidemiological data

There is relatively little epidemiological evidence on CO, so it is difficult to place the results from a few (well-conducted) studies that report positive associations in context. These studies provide the basis for exposure-response functions, but they do not give strong guidance on how representative or transferable these functions are. The new epidemiological data was not accounted for in the setting of revised air quality guidelines for CO by WHO or by EPAQS. Here the main studies are reviewed.

3.1.2.1 Acute Mortality and CO: Touloumi *et al*, 1994

Touloumi *et al* (1994) studied daily mortality data from Athens in the period 1984 to 1988. The study quantified levels of black smoke, sulphur dioxide and carbon monoxide. There was a highly significant association between daily mortality and daily CO, adjusting for temperature, relative humidity, year, season, and day of the week, giving an increase in daily mortality of 1.45% per mg/m^3 CO (24-hr mean). However, after adjusting for SO_2 and/or black smoke, this relationship became non-significant.

The finding was partially corroborated by a later study of mortality in Athens in 1987-91 (Touloumi *et al*, 1996). Adjusting as usual for time trends and climate, this later study found a statistically significant effect of CO on daily deaths, in single-pollutant models. However, the effect of CO was not examined in adjusting for black smoke or SO_2. Verhoeff *et al* (1996), studying daily mortality in the period 1986-92 in Amsterdam, found relationships with several pollutants but not with CO.

Some studies in Los Angeles, for example Kinney *et al* (1995), have shown effects on mortality, though the estimated risks were lower than those in Athens described above. There is also evidence of CO effects on mortality from some other studies.

3.1.2.2 Schwartz and Morris, 1995: Associations between cardiovascular hospital admissions and PM_{10} and CO

Schwartz and Morris (1995) examined the relationship between air pollution and cardiovascular admissions in Detroit, Michigan for people aged 65 years and older during the period from 1986 to 1989. Air pollutants considered were PM_{10}, ozone, SO_2 and CO. Daily admissions were obtained for ischaemic heart disease, cardiac dysrhythmias and congestive heart failure in the population aged 65 years and older.

Congestive heart failure (CHF) and CO

There was a significant association of CO with admissions for congestive heart failure. On adding PM_{10} to this model the association with CO *remained* significant and hence suggests an independent effect of CO. As the Poisson model was used this can be interpreted as the percentage increase in CHF admissions per increase in CO equal to 1.72% per ppm CO (1-hr max). The study provides data for the following function:

Increase in annual admissions for CHF = 55.5 per 100,000 per mg/m^3 CO (24-hr mean)

Ischaemic Heart Disease (IHD) and CO

There was also a significant association of CO with admissions for ischaemic heart disease. However, on adding PM_{10} to the model, the association with CO became non-significant.

3.1.2.3 Other hospital admissions studies, especially Poloniecki *et al*, 1997

These findings of a relationship between daily CO and hospital admissions for cardio-related causes are supported by two recent papers from Canada (Burnett *et al*, 1997a; 1997b). The CO effect in the latter was weak, possibly because summertime pollution only was examined. In Burnett *et al* (1997a), however, CO was the pollutant most strongly and consistently related to hospital admissions for congestive heart failure in the elderly. Moreover, the CO effect was insensitive to adjustment for other pollutants.

Poloniecki *et al* (1997) examined hospital admissions for various cardiovascular causes in relation to concentrations of several air pollutants on the previous day. The CO measurements were means of 24-hr measurements, expressed in units of ppm. In single-pollutant models, daily CO was significantly related to hospital admissions for acute myocardial infarction and other circulatory diseases, as well as to the more global endpoint of combined circulatory diseases. The result was, however, not confirmed after adjustment for black smoke or SO_2 or NO_2 in analyses of acute myocardial infarction using two-pollutant models.

It is difficult to be confident therefore of an effect of CO as such; and what if any hospital admissions endpoint should be used. There is a case for using the global endpoint of combined circulatory diseases from the study of Poloniecki *et al* (1997), though at the risk of over-estimating the effects. The relevant relative risk was equivalent to an increase of 2.0% per mg/m^3 daily CO.

3.1.3 Comment on consistency of reported CO effects

There is a possible problem here with consistency in the available evidence. Ischaemic heart disease concerns a reduced supply of blood to the heart. Given that a reduced supply of blood clearly leads to a reduced supply of oxygen there are good reasons for believing that increased levels of CO would cause a higher incidence of hospitalisation for ischaemic heart disease. Also, if it is accepted that CO is linked to heart disease, a link to the advancement of mortality is not surprising.

It is also necessary to ask who exactly is at risk from ambient CO exposure, and the role of ambient CO exposure in heart disease or death. It appears probable that the major cause of these problems is not exposure to ambient CO levels, but exposure to CO through smoking or faulty domestic appliances, or the health effects of poor diet, or of other factors unrelated to air quality. Under these circumstances the effect of exposure to ambient CO may simply be to advance hospital admissions or death by a few days. If this is the case, it would appear that there is a wider variety of policy options available to reach the same goal than just those measures which address CO in the ambient air.

3.2 BENZENE

3.2.1 Effects of Benzene

Effects of benzene have been detected from experimental exposures of animals (particularly mice and rats), and occupational exposures of people. Available data are summarised in Tables 3.4 to 3.6. A glossary is provided in Appendix 2 for explanation of the medical terms used. The interpretation of some of these data, particularly the human-leukaemia studies prompts much debate. Much concern relates to the extrapolation of data from high occupational levels to much lower ambient concentrations (Figure 3.1). If the effects of benzene are in any way receptor-mediated it might be anticipated that thresholds exist that would rule out any effect. Equally, however, the dominance of adult leukaemias in the observations may be an artefact resulting from the use of occupational exposure data.

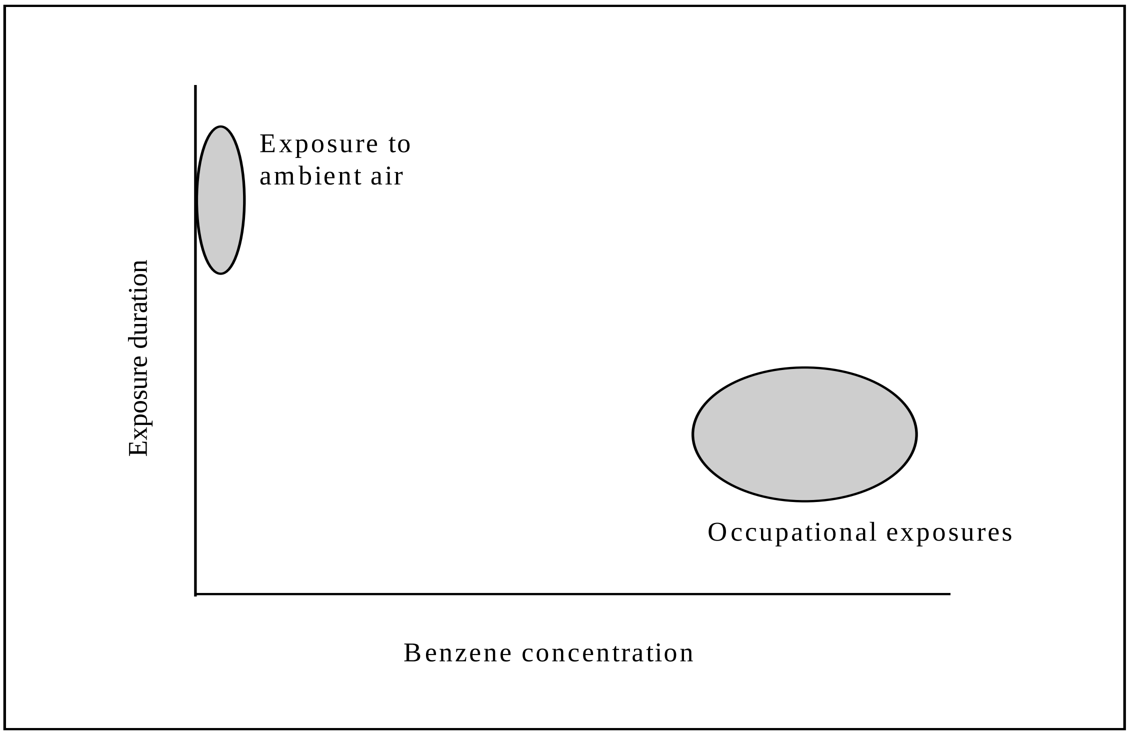

Figure 3.1. Illustration of the different characteristics of exposures to benzene in the occupational situations used for derivation of risk factors, with exposure from the ambient air.

Gennart *et al* (1994) on behalf of CONCAWE listed published lifetime risk estimates for exposure to benzene at a concentration of 1 μg/m^3 in air. These varied widely from 8.4 x 10^{-6} to 1.9 x 10^{-11}. Most estimates were of the order 10^{-6}, though the CONCAWE reviewers quoted reasons for preferring estimates at the lower end of the range. The ad hoc group convened by the Working Group on Benzene agreed to a range for risk of 5.10^{-8} per μg/m^3 to 5 x 10^{-6} per μg/m^3. Dividing by 75 (taken here as the average lifetime) provides an annual risk of 6.7 x 10^{-10} to 6.7 x 10^{-8} per μg/m^3. This allows a first estimate of the effects of exposure of the population to benzene in the ambient air. For simplicity three levels of benzene (2, 5 and 10 $\mu g/m^3$) are assumed to which the population of the European Union are exposed for a lifetime. This range of exposures is intentionally broad to ensure that it includes the mean European exposure to benzene in ambient air. The associated incidence of cancer (total cases for the EU every year) is shown in Table 3.3.

Table 3.3. First estimates of the range for the incidence of cancers across the whole of the European Union in 2010, linked to exposure to benzene in the ambient air

	Annual cases at lifetime risk factors of:	
Mean benzene exposure, $\mu g/m^3$	**$5.10^{-6}/\mu g.m^{-3}$**	**$5.10^{-8}/\mu g.m^{-3}$**
2	50	0.5
5	125	1.3
10	250	2.5

Table 3.4. Results of animal exposure studies for benzene.

Effect	**Animal**	**Exposure Levels**	**Duration of Exposure**	**Reference**
Decreases in blood cell counts	mice	320 mg/m^3 or higher 32 mg/m^3	one to several weeks 25 weeks	WHO (1993)
Leucophenia	rats	150 mg/m^3 over 960 mg/m^3	32 weeks 2 and 13 weeks	WHO (1993)
Reduced effectiveness of B-cell lymphocytes	mice	32 mg/m^3	1 week	WHO (1993)
Depressed T-cell response	mice	96 mg/m^3	1 week	WHO (1993)
Reduced resistance to infection by *Listeria monocytogenes*	mice	960 mg/m^3	5 days	Rosenthal and Snyder (1987)
Increased tumour incidence from injected polyoma virus induced tumour cells	mice	320 mg/m^3	100 days	Rosenthal and Snyder (1987)
Haematopoetic changes	mice	16-65 mg/m^3	days 6-15 of gestation	WHO (1993)
DNA damage in bone marrow, peripheral blood	mice	900 mg/m^3		Plappert *et al* (1994)

cells and liver				
Sister chromatid exchanges in peripheral lymphocytes and micronuclei in bone marrow	rats	9.6 mg/m^3 (lymphocytes) 3.2 mg/m^3 (micronuclei)		Erexson *et al* (1986)
Hematopoetic neoplasms, including thymic lymphoma	mice	960 mg/m^3	lifetime	Snyder *et al* (1980)
Malignant lymphomas, preputial gland cancer and lung tumours	mice	960 mg/m^3	16 weeks	Farris *et al* (1993)

Source: WHO paper on Benzene

Table 3.5. Observed health effects of human exposure to benzene.

Effect	**Exposure**	**Reference**
Lowered white and red blood cell counts	Occupational; above 120 mg/m^3	Cody *et al* (1993)
Structural and numerical chromosome defects	320 mg/m^3 or higher; or chronic exposure to 32 mg/m^3	WHO(1993), Major *et al* (1994), Karacic *et al* (1995)
Increased risk of acute non-lymphocytic leukaemia (ANLL)	Occupational (various levels)	Rinskey *et al* (1987), Ott *et al* (1978), Bond *et al* (1986), Wong (1987)

Table 3.6. Leukaemia deaths in workers occupationally exposed to benzene.

Study	**No. of people exposed**	**No. of deaths**	**Exposure Estimates (ppb-years** unless otherwise indicated)**	**Reference**
Goodyear Pliofilm Plant workers employed for at least one day in a department where benzene was used during 1940-1965. Deaths occurring after 1950 counted.	1165 men	2 2 2 3	1-39,990 40,000-199,990 200,000-399,990 >400,000	Rinsky *et al* (1987)
Chemical workers exposed to benzene for at least 6 months between 1946 and 1975 (only the cumulative exposure group is included)	3536 men	5 5 5	500 2000 >2000 Estimates for 30 year equivalent levels of exposure	Wong (1987)
Dow Chemical workers exposed in organic and resin synthesis (excludes confounding exposures)	888 men	3	1500 25,400 351,000 Estimates for individual cases	Bond *et al* (1986)
Coke Oven and other Coal Products workers (National Smokeless Fuels and British Steel Corporation)	3812 men 2708 women	3 2	Estimated exposure concentrations: 310-1320 ppb *	Hurley *et al* (1991)
Chinese Factory Workers exposed to benzene in painting, shoe-making rubber synthesis, leather, and adhesive and organic synthesis factories	15,643 men 12,187 women	17 8	Concentrations where leukaemias occurred: (2000-345,000 ppb)*	Yin *et al* (1987)

* No data for duration of exposure given. Source: EPAQS (1994) Benzene. ** 50,000 ppb-years would be equivalent to a 10 year exposure to 5,000 ppb, or a 25 year exposure to 2,000 ppb.

3.3 ADDITIONAL CONSEQUENCES OF ABATEMENT MEASURES FOR CO AND BENZENE

Abatement of CO and benzene will change the magnitude of other burdens (such as risk of accidents, release of pollutants other than CO and benzene) and their associated impacts. Some examples are listed in Table 3.7. Most of the effects listed in the table will lead to additional benefits, though there is a possibility that some will not[3].

Table 3.7. Additional consequences following from the abatement of CO and benzene. The list provides examples of the effects concerned. It is not intended to be exhaustive.

Abatement measure	Burden affected	Impacts affected
Road pricing, traffic calming, public transport subsidies, etc.	Emission of all transport pollutants (SO_2, NO_x, PM_{10}, VOCs, CO_2, formation of ozone and other secondary pollutants.)	Effects on health, materials, ecology
	Risk of accidents	Death and injury, material damage
	Congestion	Travel time
	Noise	Amenity
Emission constraints	Emission of all transport pollutants (SO_2, NO_x, PM_{10}, VOCs, CO_2 etc.)	Effects on health, materials, ecology

Much thought was given during the study as to whether these effects should be considered in the analysis. It was concluded that they should not, given that the analysis is conducted expressly in relation to CO and benzene. Inclusion of benefits from reducing PM, SO_2 and NO_2 (which our scenarios assume meet limits from the outset) would appear to contradict the Commission's process for controlling those pollutants. In any case, the use of legislation on benzene or CO for control of a host of other traffic related burdens seems a very blunt instrument, and one that is unlikely to lead to the identification of an optimal package for dealing with these other burdens.

On this issue it was concluded that it would be better in the future to have an all-inclusive analysis that seeks to strike a balance between the control of all pollutants that come under the Framework Directive on Ambient Air Quality. A recent proposal by the Commission for a programme entitled Clean Air For Europe (CAFE) seeks to do this and more, integrating also Directives on emissions.

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[3] For example, a reduction in congestion from road pricing would probably lead to an increase in traffic speed. This could adversely influence accident rates, and the chance of serious injury or fatalities in accidents.

3.4 ESTIMATING EXPOSURE TO CO AND BENZENE

Assessment of CO effects can be made against urban background concentrations, as this is the metric used in the exposure-response relationships adopted from the epidemiological literature. This implicitly accounts for people moving between areas of different concentration. For benzene it is necessary to derive some estimate of exposure in order to use the functions derived from the workplace exposure data. Estimated daily intake of benzene under different conditions is shown in Table 3.8 (EPAQS, 1994). The EPAQS analysis was carried out using methods and data from WHO. The assessment of intake from ambient air assumed a concentration of 1.6 $\mu g\ m^{-3}$ as a rural daily mean, and 40 $\mu g\ m^{-3}$ as the urban maximum daily mean based on measurements in Central London. The urban level is very high in the context of this study as reference to the results in Chapters 5 and 6 will demonstrate.

Table 3.8. Estimated daily intake of benzene (from EPAQS, 1994)

Source		**µg intake**
Ambient air -	rural	15
	Urban	400
Cigarette smoke -	10/day	300
	20/day	600
Food		100 - 250
Water		1 - 5
Total -	Minimum	120
	Maximum	1,250

This table suggests that most variation is linked to the places where people live and work, and to whether they smoke or not. Further data on exposures are given in Table 3.9, taken from Gennart *et al* (1994). This further highlights the problems of extrapolation of benzene data for derivation of exposure-response relationships.

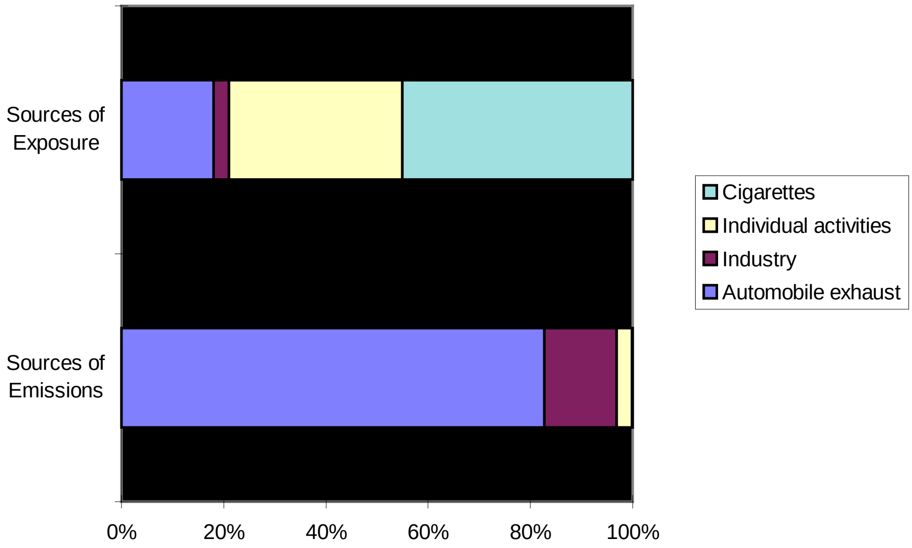
Table 3.9. Typical estimates of daily absorbed dose for specific situations (excluding diet).

Specific Situation	Exposure ($\mu g/m^3$)	Time (hours)	Alveolar ventilation rate (m^3/hr)	Retention (%)	Absorbed dose (µg/day)
Occupational exposure	1600	8	1.25	50	8,000
Smoking	30 µg /cigarette	20 cig/day	-	50	300
Passive smoking	3.5	14	1	50	25
Driving	40	1	1	50	20
Refuelling	3200	5 min/week	1	50	20
Outdoor, urban	20	1	1.25	50	13

Outdoor, rural	1.6	1	1.25	50	1
Indoor, non-smoking	7	14	1	50	50

In addition to this, Ott and Rogers suggested that cigarettes and consumer products may make a much larger contribution to benzene exposure in the general public than do sources such as vehicle exhaust fumes and industry. They quote Wallace (1995) who estimated that about 45% of total exposure to the US population comes from smoking or breathing smoke exhaled by others, 36 percent from inhaling gasoline fumes or using common consumer products (glues etc.) and 16% from other home sources such as paints and gasoline stored in basements or garages. Only 3% of the total exposure is estimated to come from industrial sources. This contrasts with the breakdown of benzene emission sources for the US, as shown in Figure 3.2.

Figure 3.2. US sources of benzene emissions and associated exposure.



It is unclear whether these findings would be fully applicable to Europe, as there are likely to be differences in the composition of consumer products. US consumer products that contain benzene are said to include glues, adhesives, household cleaning products, paint strippers and some art supplies. However, a preliminary investigation of such products in the UK has found no evidence of the presence of benzene. Dulux, Polycell and Ronseal, major manufacturers of paints, glues and varnishes, have all confirmed that their products contain no benzene. Figure 3.2 does however demonstrate that the full problem of benzene exposure is related to a number of other sources not considered within this study because it would be inappropriate to deal with them through legislation on ambient air quality. The fact that there are other important sources of exposure does not of course in itself negate the need for legislation on benzene in the ambient air.

The risk factors used in the presents study are linear, extrapolated back to zero. Non-linearities, for example through the existence of thresholds, would lead to lower benefits from measures to reduce concentrations of benzene. Assuming the assumption of linearity to be correct, there is no need to account for non-ambient sources of benzene (for example through smoking, which could take some members of the population above a threshold even with no consideration of exposure through the ambient air). However, given the nature of the functions it is necessary to consider the way in which dose from the ambient air is built up as people go about their normal activities.

The pollution scenarios used in this study provide estimates of concentrations in the urban background and in peak locations within each grid cell. A range can clearly be generated assuming that everyone spends all of their time in one location or the other. Actual exposure should lie somewhere between these two positions. In order to estimate where, it is necessary to define the activities that the population undertake. There is no definitive guidance on this, though some data are available. Table 3.10 provides information collected in Paris (Société francaise de santé publique, 1996).

Table 3.10. Distribution of population exposure to benzene in Paris (from Société francaise de santé publique, 1996).

Site	Daily exposure	Benzene level μg/m^3
Underground parks	<0.5 h	100 -300
Road tunnels	several minutes	100 - 400
Cycle routes	0.5 to 1 h	-
Drivers	1 to 4 h	30 - 80
Bus passengers	0.5 to 2 h	15 - 35
Metro users	0.5 to 3 h	5 - 15
Pedestrians	1 to 3 h	10 - 30
Employed people	8 to 24 h	15 - 25
Primary schools	6 to 8 h	4 - 25
People not in employment	12 to 24 h	4 - 7

Additional data were collected in Denmark (Raaschou-Nielsen *et al*, in press), in a study investigating the exposure of children to benzene, toluene and xylene. Measurements at the front doors of houses provided highly significant relationships with benzene exposure. The slope between exposure and front door concentration in Copenhagen was 0.65, and in rural areas, 0.84. Activities that were particularly related to benzene exposure were riding in a car, and anything leading to exposure to gasoline vapours. Interestingly, passive smoking did not have a significant effect on exposure, apparently confirming some previous results.

For the purposes of this study the following model for exposure was developed (Table 3.11). It has been kept reasonably simple. It is assumed that there is a 1 to 1 relationship between outdoor air concentrations and the level of benzene attributable to outdoor air within buildings. The data given are largely the authors' own estimates, building on the other data presented here. The consideration of indoor exposure is problematic partly because the legislation on air quality does not apply indoors or in the workplace. However, given the obvious link between outdoor and indoor air quality it is clearly relevant to include the effects of exposure indoors from external sources.

Table 3.11. Preliminary estimates of the time spent by different groups in different locations. Results apply to the urban population only. No account is taken in the analysis of those who commute into cities from outside the modelled domain for each city.

Group	% of population	Location	Level	hours/day spent in each location
Infants (<3 years)	5	At home	Background	18
		In transit	Peak	1
		Outdoors	Background	4
		Outdoors (e.g. shops)	Peak	1
Schoolchildren	15	At home	Background	14
		In transit	Peak	1
		At school	Background	6
		At school	Peak	2
		Outdoors	Peak	1
Those working indoors	40	At home	Background	12
		In transit	Peak	2
		At work	Background	9
		Outdoors	Peak	1
Those working outdoors	5	At home	Background	12
		In transit	Peak	2
		At work	Peak	8
		Outdoors	Peak	2
Adults not in employment	35	At home	Background	18
		In transit	Peak	2
		Outdoors	Peak	2
		Outdoors	Background	2
Overall	100		Peak	4 (16%)
			Background	20 (84%)

Available data from the literature on indoor/outdoor concentrations were found to be conflicting. More robust (though preliminary) data were, however, made available to the study team from participants in the Macbeth project (Table 3.12: Cocheo, 1998, personal communication) which is monitoring atmospheric concentrations of benzene and exposures in European towns and homes. Results are still conflicting; the trend in Athens is opposite to that elsewhere. Overall the ratio of urban background to total exposure is 2.2, within the range 0.9 to 3.2. On average this suggests that our model from Table 3.11 would underestimate exposure by 33% (based on time spent in peak concentration locations, combined with a central estimate of the ratio between concentration in urban background and hot-spot locations given in Chapter 5). However, this is well within the range suggested by the Macbeth data.

Table 3.12. Comparisons of urban background, indoor levels and exposures (preliminary results from the Macbeth programme).

Location	Indoor level, µg/m^3	Urban background, µg/m^3	Exposure, µg/m^3	Exposure /urban background ratio
Copenhagen	6.1	4.0	8.2	2.1
Antwerp	11.9	4.6	14.9	3.2
Rouen	10.4	5.3	14.6	2.8
Padova	10.3	9.6	14.9	1.6
Murcia	31.0	14.5	37.4	2.6
Athens	12.5	23.0	21.8	0.92

One possible reason for underestimation by our model is that it does not take account of variation in emissions over the day. This is illustrated by data taken from the Auto Oil air quality report (Figure 3.3). The annual average concentration in 'peak' locations (busy streets, etc.) seems likely to underestimate actual exposure in the periods of time that most people spend in these locations. Data used to generate Figure 3.3 suggest that emissions in rush hour are roughly 40% higher than the daily average. Application of the exposure model at the moment essentially assumes that people are confined to the grid cell in which they live. This seems reasonable for infants, school children and adults who are not in employment, but not, on the whole, for employed adults, who will tend to migrate towards the city centre for work, which will tend to increase their exposure. Overall these factors would suggest that the proposed exposure model might tend to underestimate exposures.

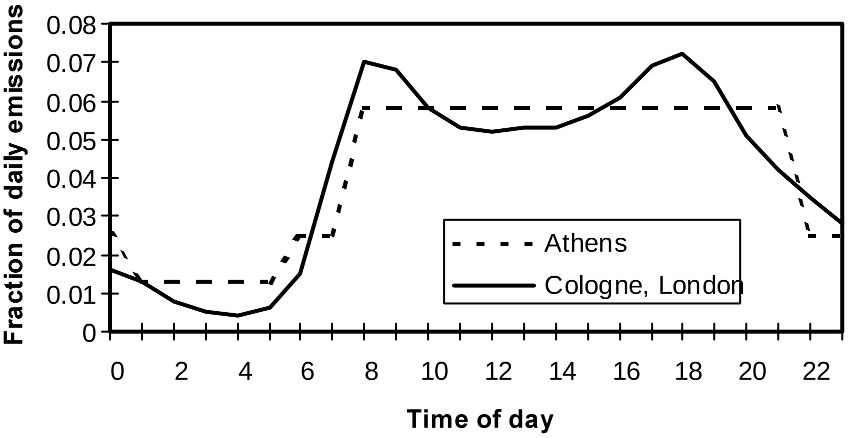


Figure 3.3. Fraction of emissions from mobile sources in each hour of the day in Athens, Cologne and London. Data are taken from the Auto Oil air quality report (European Commission DGXI, 1996).

4 Reduction of CO and Benzene Emissions from Mobile Sources

4.1 OVERVIEW

It was noted above that the dominant source of both CO and benzene of interest here is transport. This Chapter therefore describes the options for reducing emissions of carbon monoxide and benzene from mobile sources. These options can be broadly split into three categories:

- ***Technical options*** which can reduce pollutant emissions by improving vehicle technology, including alternative fuels and inspection & maintenance programmes;
- ***Management options*** which can reduce pollutant emissions by promoting the most economically and environmentally efficient use of road space;
- ***Policy options*** which set the context for the take-up of other options, including economic and regulatory measures.

Appendix 5 provides a review of the abatement of benzene from stationary sources. Although these are of very limited application in this study, they could become much more important in future revisions to the daughter Directive, and so have been retained to complete the picture.

To date, the use of technology to reduce vehicle emissions has focused on “end-of-pipe” and “front-of-pipe” solutions. Catalytic converters (for petrol vehicles), advanced engine technology and management systems and “cleaner” fuels have been, and will continue to be, used to meet current and future EC emissions regulations. Management and policy options -collectively termed ‘non-technical’ measures, seeking to affect emissions by changing the behaviour of polluters - look set to grow in importance for eliminating exceedences of statutory air quality standards in specific locations.

Within the following discussion, the assessment of ***technical*** options will be made on the feasibility and technical effects, and the assessment of non-***technical*** options on the feasibility and effects of measures that may be available.

The use of options in combination will often be necessary to meet air quality targets. For example, the considerable technological improvements which are being used to meet EURO II and EURO III emissions standards may have to be complemented by the use of even “cleaner” technologies in niche markets or by traffic restraint in order to attain air quality targets in particular ‘hot-spot’ areas.

A list of options of the possible options available for abating CO and benzene from transport is presented in Table 4.1 below. This list excludes those options that are already in place or will be introduced under pending legislation. It should be stressed that some of the abatement options listed will be rejected at a later date, prior to further cost analysis, on the basis that these options are not commercially developed or technically feasible.

Table 4.1. Options for abatement of transport related emissions of CO and benzene.

	Category	Option
Technical Options	Tailpipe treatments	• Advanced catalysts
	Engine controls	• Lean burn engines • Exhaust gas re-circulation
	Improved durability of emission control systems	• Increased severity and frequency of compulsory inspection and maintenance checks • On-board diagnostics • Remote roadside sensing • Extension of manufacturer's liability • Conformity of Vehicles in Circulation (CVC) programmes
	Alternative fuel types / composition	• Reformulated fuel 'packages' • Alternative fuels (CNG, LPG, biofuels)
	Alternative drive-trains	• Electric vehicles • Hybrid vehicles
	Evaporative emission controls	• Improved fuel system and larger carbon canister
Management Options	Demand management	• Traffic restrictions • Traffic speed regulations
	Congestion reduction	• Traffic light controls, e.g. UTC systems
	Encouraging modal shift	• Reduced public transport fares • Park-and-Ride • New transport systems • Public transport priority • Freight subsidies
Policy Options	Economic	• Road Pricing* • Higher fuel taxation • Tax differentials to promote cleaner fuels/emission taxes • Differentiated vehicle purchase taxes to promote lower emitting vehicles • Subsidies for scrappage of old vehicles
	Regulation	• Vehicle emissions standards • Fuel quality standards • I&M programmes

* also qualifies as a demand management tool.

4.2 TECHNICAL MEASURES

4.2.1 Tailpipe treatment technologies

Both petrol and diesel emissions can be reduced by exhaust treatment. The advantage of this form of emission control is that it can be applied to existing vehicles. The most promising of these technologies are advanced catalysts for petrol vehicles.

Heated catalysts for petrol vehicles have a significant potential for reducing emissions. The aim of these systems is to bring the catalyst to its operating temperature as soon as possible after cranking the engine, hence increasing its cold-start effectiveness considerably. Costs have come down dramatically over recent years. Alternatively, closed coupled catalysts achieve very impressive hydrocarbon emission figures without reverting to a heated catalyst.

4.2.2 Engine controls

Improved electronic engine controls can achieve significant reductions in emissions by maintaining the engine at an optimum air-fuel ratio. The most promising technologies are exhaust gas re-circulation (EGR) systems and lean burn engines.

EGR is particularly aimed at reducing NO_x, but current systems have the disadvantage that they affect the drivability of the car. Enhanced, future systems will be controlled electronically through the central control unit and will also be monitored by an on-board diagnostics system.

Lean burn engines run at high air-fuel ratios only at light loads; they run at rich air-fuel ratios at high loads to maximise power. Modern lean-burn engines commercialised recently in Japan improve vehicle fuel economy by 8 to 10 percent. A disadvantage of lean-burn engines, however, is that they cannot use conventional 3-way catalysts.

4.2.3 Improved durability of emission control systems

Significant reductions in vehicle emissions can be achieved by reducing the rate of deterioration in the emissions control systems. The Auto Oil Programme identified the following mechanisms for achieving this:

- Increased severity and frequency of compulsory inspection and maintenance checks;
- Extension of the manufacturer's liability for the performance of the emission control systems from 80,000 to 160,000 km;
- Electronic sensors installed on the vehicle to monitor the performance of the systems (on board diagnostics);
- Re-call procedures (e.g. Conformity of Vehicles in Circulation (CVC) programmes) whereby models can be re-fitted if their emissions performance deteriorates beyond an acceptable level;
- Improved mechanisms for the remote roadside detection of vehicles emitting above acceptable levels.

4.2.4 Alternative and reformulated fuels

The use of alternative fuels to petrol and diesel have the potential to bring about significant reductions in CO and benzene emissions (ETSU, 1996). Their application is particularly suited to fleet operators who can dispense fuel from a central depot to vehicles operating in a limited geographical area. Thus the use of alternative fuels in buses, taxis or light delivery vehicles could play an important role. The summary of the Cost-effectiveness report of AOP I (Touche-Ross, 1995, p. liii) finds that the use of liquefied petroleum gas (LPG) fuelled buses in areas of high local pollution appears to be more cost effective in controlling NO_x levels than higher technical standards applied to passenger cars throughout the EU. However, ETSU (1996) found that LPG driven buses could emit double the CO that a bus running on diesel emits.

Possible alternative fuels include compressed natural gas (CNG), LPG, methanol (MeOH) and ethanol (EtOH). In addition, electric vehicles have a potentially important role in helping to improve urban air quality because of their zero emissions at point of use. Of course, the emissions associated with electric vehicle operation are dependent upon the characteristics of electricity generation. However, even if total electric vehicle emissions are higher (i.e. in the amount of CO produced), their comparative environmental impact (and their effect on air quality levels in areas where air quality is of most concern) is usually low as they are not released in highly populated urban environments.

A number of manufacturers have expressed their belief that fuel-cell powered vehicles will be on the market within 5 years in significant numbers. However, it would seem unlikely that the take-up of these vehicles would make a substantial difference to air quality on the time scale of interest here (to 2010). Use of fiscal measures could of course push sales of these and other relatively benign technologies.

The introduction of alternative fuels into the market will be dependent upon a number of factors such as competitiveness, harmonisation of fuel distribution, availability of vehicle technology, security of fuel supply and availability of maintenance services. It is widely perceived that LPG, CNG and electric are the most likely fuels for early introduction, largely because of their overall cost advantage compared to other alternatives.

A fuel modification "package" is defined as a fuel for which the values of certain environmentally relevant parameters conform to confined limits (CEC, 1996). These parameters for re-formulated fuels contained in the fuel packages were defined in AOP I and include benzene.

4.2.5 Evaporative emission controls

The introduction of a more stringent evaporative emissions test procedure for gasoline cars has recently been discussed in Europe. In contrast to the US specification, the proposed European specification would exclude on-board vapour recovery. The major changes required to the vehicle relate to the fuel system. Improvements are required in the pipework, connectors and fuel tank. A larger carbon canister is also required. This type of measure may be of particular interest in the southern European countries where high temperatures make evaporation from vehicles a matter of greater concern than in the north.

4.3 NON-TECHNICAL MEASURES

The measures listed in Table 4.1 also include management measures (which alter transport demand) and policy options, such as market based policy instruments, that aim to induce polluters to meet the specified compliance levels. These options are discussed in turn below.

4.3.1 Management options

Traffic management options for reducing vehicle emission can be grouped as follows:
- Traffic restraint;
- Congestion reduction;
- Encouraging modal shift.

Both the effects of these measures on emissions and their costs are very difficult to predict because they act on emissions indirectly through price or regulatory mechanisms that in turn affect consumer behaviour.

Traffic Restraint
Schemes that reduce the total volume of traffic in an area will tend to be associated with reduced emissions. However, where such changes cause a redistribution of traffic then environmental disbenefits can also be expected.

Road pricing is increasingly being considered by policy makers as a potentially cost-effective means of reducing congestion. It has the dual effect of reducing the total volume of traffic and encouraging passengers to move from private to public transport. The EUCARS simulation model used in AOP I predicted a reduction in emissions in *urban* areas by 4 to 6% for an increase in road travel costs of 10%, rising to 18 to 25% for an increase in road travel costs of 50%. There would be slightly lower *total* emissions reductions ranging from 1.6 to 2.6% for a 10% increase rising to 18 to 23% for a 50% increase.

AOP I concluded that road pricing was potentially the most cost-effective local management measure available for emissions reductions. There are, however, a number of problems with road pricing. It is highly capital intensive, requiring significant investment outlays. In addition, the technology for charging still remains to be tested for large schemes. There is also a problem of equity, in that road user charges would hit the poorest motorist hardest.

Traffic restrictions or bans are important tools of traffic management. Traffic restriction policies may be reinforced by parking policies to limit the supply or increase the price of parking in central areas. Particular types of traffic restriction schemes are:
- Licence plate bans, where vehicles are allowed to enter an area on alternate days only, the days being determined on the basis of the license plate;

- Permit entry systems, where access to areas is restricted to defined groups such as residents or commercial vehicles only;
- Total area bans, where all traffic is restricted from a usually small central area.
- Road closures during exceedence episodes

AOP I predicted that traffic restraint may have some potential as a method of reducing emissions in areas of high local pollution.

The direct costs of traffic restrictions are quite low. Putting in place traffic restrictions typically involves some capital investment for signs and minor highway works to impede traffic. There are, however, additional indirect costs for motorists related to the additional time spent making journeys.

Congestion Reduction

Schemes that reduce congestion tend to reduce emissions due to the reduction of stop/start operations. There are many different types of urban traffic control systems (UTC). Table 4.2 summarises the different types and shows estimates of changes in fuel consumption, where these have been estimated.

Table 4.2 - Impacts of UTC Systems

System	Change in Fuel Consumption
TRANSYT fixed time signal co-ordination set to minimise delay compared to uncoordinated signals	up to -15%
Planned green wave allowing smooth driving at 40 km/h	-16% (Caen)
SCOOT signal co-ordination compared to fixed time	-9% (Glasgow / Coventry) -5% (Worcester)

Source: TRL (1995).

A number of large towns and cities in Europe already have some form of UTC system, so there is only limited potential for achieving further emissions reductions. However, UTC systems are being extended to integrate traffic and environmental monitoring and management and there are also potential environmental benefits indicated by using UTC systems to give priority to public transport vehicles and to achieve area wide traffic restraint.

Encouraging Modal Shift

Schemes that encourage a change from private car use to public transport should produce net emissions benefits although disbenefits may also occur due to increased flows of public transport. Modal shift measures include:

- Park-and-ride;
- New transport systems;
- Public transport priority;

- Reduced public transport fares;
- Freight subsidies.

Park-and-Ride schemes have the potential to reduce car use within the inner city area but the extent to which this is achieved has not been well documented. They may also stimulate additional trips and trips with further distances. For these reasons, together with the fairly high investment costs required, park-and-ride may not be a cost-effective option for reducing emissions.

Similarly, **new transport systems** require a very high capital cost for questionable emissions benefits. It is only with the use complementary car restraint policies that the benefits of new, attractive public transport systems will be realised.

Bus priority measures can significantly increase service reliability, reduce journey times and bus emissions, but may increase emissions from other vehicles. Thus the overall effect on emissions can sometimes be small.

The evidence from **reduced public transport fares** is that they result in significantly increased patronage, but only a small decrease in car use. The reason for this is that the lower prices release suppressed demand among the poorer members of society for whom the previous price was too high, but do not offer enough benefit to entice car users away from their cars. For example, with a 40% reduction in public transport fares, AOP I predicted a 49% increase in public transport use and a 5.6% reduction in total car mileage. As this shows, the potential for emissions reductions of reduced fares is limited, unless undertaken in conjunction with other measures to encourage modal switch (such as road pricing).

Freight subsidies for alternative modes of road freight (HGVs) have the potential to significantly reduce emissions and congestion in both urban and non-urban areas. The available evidence suggests, however, that this is relatively expensive and as such freight subsidies may not be the most cost-effective method of reducing pollutant emissions.

It should be stressed that the effectiveness of all modal shift options can be enhanced significantly when in combination with other measures such as road pricing or traffic restraint.

Finally, with all these local traffic management options, limited cost data are available. Moreover, there is no consistent methodology for proportioning costs between pollutants.

4.3.2 Policy options

Policy measures set the context for the take-up of other options. Again there are a range of policy options to reduce emissions of CO and benzene from the transport sector. These can be split into two main categories:
- Economic and fiscal measures;
- Regulatory measures.

4.3.3 Economic and fiscal measures

There are several ways in which fiscal policy could be used to reduce road transport emissions. These range from increased taxation to reduce the total level of transport activity, to differential taxation to encourage the use of the less polluting vehicle types.

Fuel Tax

Increased fuel taxes have the potential to reduce emissions by encouraging consumers to:

- Travel less by car;
- Drive more frugally; and
- Purchase more fuel-efficient vehicles.

In addition, fuel taxes provide an incentive to vehicle manufacturers to produce more fuel-efficient vehicles. Higher fuel taxes are easy and cheap to implement, and directly target fuel use and therefore emissions. The Auto Oil study suggests that increases of fuel tax of 70% can reduce emissions by 10 to 15%. However, higher fuel taxes have limitations as they result in significant welfare costs for motorists. In addition, this form of taxation is regressive and has no way of targeting those areas where the greatest reductions in emissions are required.

Differential Fuel Tax

These fuel taxes can be used to alter the tax differential between petrol and diesel. The use of the price mechanism is a very effective method of achieving the desired outcome, as the rapid introduction of unleaded fuels in the EU since the late 1980's has demonstrated. In addition, it is also very simple to administer. The main problem with this approach, however, is that although certain target pollutants may be reduced, there will be knock on effects on the other emissions, which may lead to increases.

Vehicle Purchase Tax

The use of taxation to increase the cost of transport and thereby reduce the level of traffic is another option. However, because of the very low elasticities of demand observed in the transport sector, significant increases would have to be made before any noticeable reductions were made. This option also has the negative side-effect of increasing the average age of the car fleet, therefore increasing emissions. In addition, this form of taxation is regressive and has no way of targeting those areas where the greatest reductions in emissions are required.

Structured vehicle purchase taxes can achieve improvements in the average fuel consumption of the vehicle fleet, rather than emissions reductions per se. The EUCARS simulation of the Auto Oil study suggests that fuel consumption per km is reduced by up to 3.4%. However, the relative impact on emissions (other than CO_2) is very small at less than 1% even for the highest rate of tax (700 Euro for every litre per 100 km in excess of the target level of 3 litres per 100 km).

Scrappage Subsidies

Scrappage subsidies are grants paid by the government to the consumer on release of old vehicles for scrappage. These may be used as a policy tool to reduce overall emissions from the vehicle parc. However, the emissions benefits of such a policy are generally low (roughly 1%). This is largely because there is no simple relationship between the age of a vehicle and its emissions characteristics. Also, as scrappage incentives are typically provided to all vehicles above a certain age irrespective of their emissions characteristics, they are quite costly to implement. Higher benefits might be achieved if scrappage schemes were to be considered in conjunction with policies to raise the emissions standards of the new replacement vehicles. In this context the scrappage subsidy would enhance the effectiveness of technical measures by accelerating the rejuvenation of the vehicle fleet.

It is possible that scrappage schemes could be refined, so that they are better targeted at the most polluting vehicles. It is worth noting the reported success of a scheme introduced in Italy, where more than 20,000 vehicles were scrapped soon after the introduction of the scheme. Government expenditure was more than matched by increased revenues from new car sales that were apparently linked to the scrappage scheme (press reports). AOP I reported that a well designed scrappage scheme may be particularly effective in Greece, given the extremely low rate of vehicle replacement there (Touche-Ross, 1995).

Although fiscal policies can be very effective, they frequently lack the focus necessary for them to be cost-effective policy tools for meeting air quality targets when compared to well targeted regulation. In addition, their effect is gradual, making them unsuited for tackling the problem of peak air pollution concentrations.

4.3.4 Regulatory measures

There is a range of regulatory policy options available to reduce emissions of CO and benzene. These include:
- Vehicle emissions standards;
- Fuel quality standards;
- Inspection and Maintenance programmes.

Many of the measures associated with vehicle emission standards and inspection and maintenance programmes have already been described above. Although fuel quality standards may offer some benefit, care must be taken in introducing such measures. Research has shown that although CO and benzene emissions can be reduced by reducing the aromatic content of fuel, this can increase NO_x emissions for certain drive cycles and engines, maybe because of the efficiency over the catalyst for low aromatic fuels (EPEFE). There will also be additional knock-on impacts to upstream industries, such as oil refineries.

4.4 COSTS OF ABATEMENT OPTIONS FOR MOBILE SOURCES

4.4.1 Emissions

Most data on control measures are in terms of cost per vehicle and % emission reduction per vehicle. In order to determine overall cost per tonne abated for given ambient concentration and therefore emission targets, it is necessary to estimate the emissions per vehicle expected for 2010. Data on emissions per vehicle were taken from UK sources (Department of Transport 1995), cross checked with the AOP I assumptions and subsequent decrease relating to the Directives that followed AOP I. This demonstrates that by 2010 each vehicle would emit approximately 50 kg of carbon monoxide and 0.5 kg of benzene per year.

4.4.2 Cost curves

Assumptions
In order to calculate a cost curve, assumptions need to be made about:
- the likely measures which can be adopted,
- their range of costs,
- potential penetration (market share, or adoption of abatement measures), and
- subsequent range of efficiencies.

Table 4.3 details the assumptions that were used, based largely on the findings of the Auto Oil project. Penetration appears to be static in the Table, as it deals with *potential* in the time available before full implementation of the proposed Directive.

Table 4.3. Assumptions relating to the development of the Cost Curve.

Measure	Cost Euro per vehicle		Penetration				Efficiency with respect to benzene		Efficiency with respect to CO	
	Min	Max	C	LG	B	HG	Min	Max	Min	Max
Lean Burn De NO_x	85	255	0	0.5	1	1	50	60	50	60
Advanced Catalyst	40	50	1	0.5	0	0	10	20	10	20
Traffic Restrictions	100	137	1	1	1	1	2	8	1	3
Inspection & Maintenance	110	2090	1	1	1	1	26	61	28	66
Road Pricing	440	1265	1	1	1	1	1	12	2	15
Improved Vehicle Design	150	450	1	1	1	1	20	50	20	50
Emissions based Purchase Tax	797	2585	1	1	1	1	16	52	19	44
Fuel Reformulations	100	450	1	0.5	0	0	20	30	5	15
CNG LPG LG Vehicles	610	1830	0	1	0	0	90	100	90	100
Engine Control Systems	50	150	1	1	1	1	20	40	20	40
Electric vehicles	4500	13500	1	1	1	0	100	100	100	100
Subsidised Public Transport	-55	1017	1	0	-1	0	90	100	90	100
CNG Buses	9000	15000	0	0	1	0	90	100	90	100

C - Cars
LG - Light Goods
B - Buses
HG - Heavy Goods

Further considerations that were made are as follows:

- Regulations will come into effect by 1999 and to all intents and purposes the bulk of the fleet will comply with these regulations by 2010.

- The number of km travelled by vehicles, the vehicle fleet growth, fuel consumption, traffic densities etc. are as assumed in the Auto Oil programme. The national CO and benzene emission in 2010 is therefore deemed to be directly proportional to the emission rate from vehicles in terms of g/km.
- Where a range of cost effectiveness figures were unavailable, figures50% above and below the stated figure were used to construct a range.

Scenarios

The cost curve is constructed by progressively employing control techniques of varying cost and efficiency, until the pollutant is abatement is as much as technically feasible. Since abatement techniques are not always compatible (for example buses would not be fitted with lean burn De-NO_x, converted to LPG and finally used on electrified lines) different scenarios are constructed from existing control techniques. Three scenarios were considered for preparation of the cost curves. These are listed in Table 4.4.

The most cost effective (in terms of efficiency/cost) is applied first, with progressively less and less efficient techniques included to achieve the maximum reduction. In this way the characteristic shape of the cost curve is produced, with the initial slope corresponding to high reduction/low cost changing direction to give the low reduction/high cost part of the curve.

If each technique is assigned a single ‘best estimate’ cost and efficiency, then a single ‘best estimate’ curve will be produced. It is more realistic however to indicate the uncertainty in current understanding by considering each technique to have a range of costs and efficiencies.

Each technique is assigned a maximum and minimum cost and a maximum and minimum efficiency. The worst case might in theory be the sum of all the maximum costs and minimum efficiencies (and the corresponding best case, the sum of all the minimum costs and maximum efficiencies). From a risk analysis perspective this is so unlikely as to be an unhelpful assessment of the likely range of overall costs and efficiencies.

To achieve a more realistic assessment, a simple risk analysis model has been applied. In this model, the actual value of the cost and efficiency of each technique is considered to lie with equal probability anywhere within the quoted range. A random sample of possible costs and efficiencies is then taken, the order of techniques adjusted to reflect their cost effectiveness and a cost curve constructed.

This operation is repeated hundreds of times until a normal distribution of likely cost curves is obtained with convergence of less than 2% around the mean, 10th percentile and 90th percentile. This operation is carried out for each of the scenarios and all the data are then plotted on a final cost curve, which is used to draw conclusions about the likely cost of achieving different reduction targets. To perform these calculations the @Risk software provided by the Palisade Corporation was used.

Of the three scenarios, Scenario C: Catalysts provided the most cost effective solution for the required emission reductions. The cost curves for Scenario C are reproduced below.

Table 4.4. Scenarios used in the construction of the benzene and CO cost curves.

Scenario	Measures included
Scenario A - Electric Vehicles	Lean Burn De NO_x Traffic Restrictions Inspection & Maintenance Road Pricing Improved Vehicle Design Emissions Based Purchase Tax Engine Control Systems Subsidised Public Transport Electric Vehicles
Scenario B - CNG /LPG Buses	Lean Burn De NO_x Advanced Catalysts Traffic Restrictions Inspection & Maintenance Road Pricing Improved Vehicle Design Emissions Based Purchase Tax Fuel Reformulation CNG LPG Light Goods Vehicles Engine Control Systems Subsidised Public Transport CNG LPG Buses
Scenario C - Catalysts	Lean Burn De NO_x Advanced Catalysts Traffic Restrictions Inspection & Maintenance Road Pricing Improved Vehicle Design Emissions Based Purchase Tax Fuel Reformulation Engine Control Systems Subsidised Public Transport

The cost curves

The cost curves generated from the above procedure for benzene are reproduced in Figures 4.1, 4.2 and 4.3, and for CO in Figures 4.4 and 4.5. Given the way that the curves are generated the individual points shown do not correspond to specific measures. Figures 4.1/4.4 show the curve considering all measures identified, and Figures 4.2/4.5 the same, but with the y-axis logged. Figure 4.3 shows the curve for benzene with traffic management measures excluded. In this case it was found that reduction of benzene beyond 80% was unlikely to be technically feasible. All data are in 1995 Euro.

Application of the cost curves

The cost curves are applied by combining them with data on emissions/vehicle and the % reduction calculated in the analysis of exceedence concentrations.

Figure 4.1. Impact of uncertainty on the cost per vehicle of benzene reduction measures, with 10 and 90 perrcentiles shown.

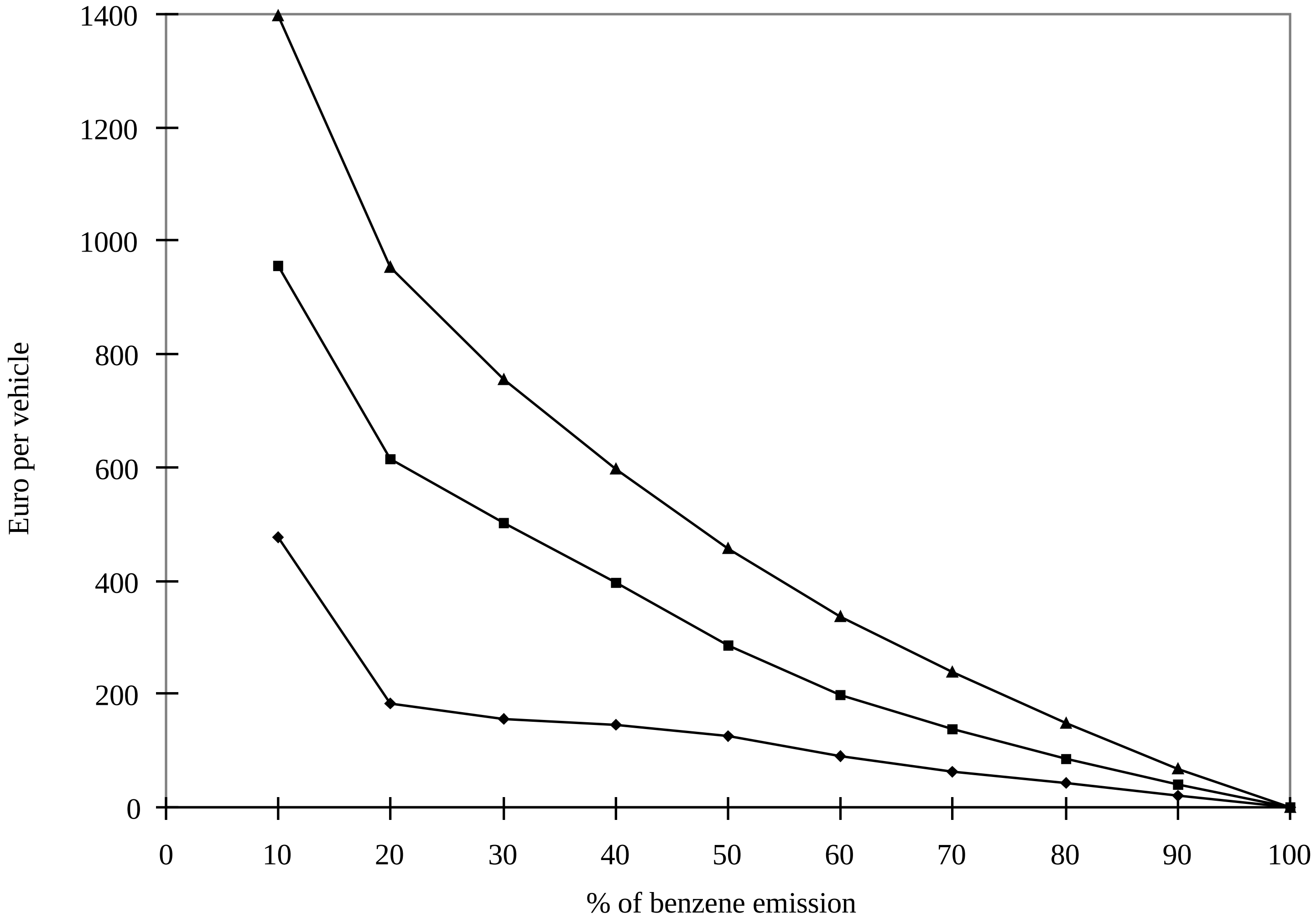


Figure 4.2. Impact of uncertainty on the cost per vehicle of benzene reduction measures with 10 and 90 perrcentiles shown.

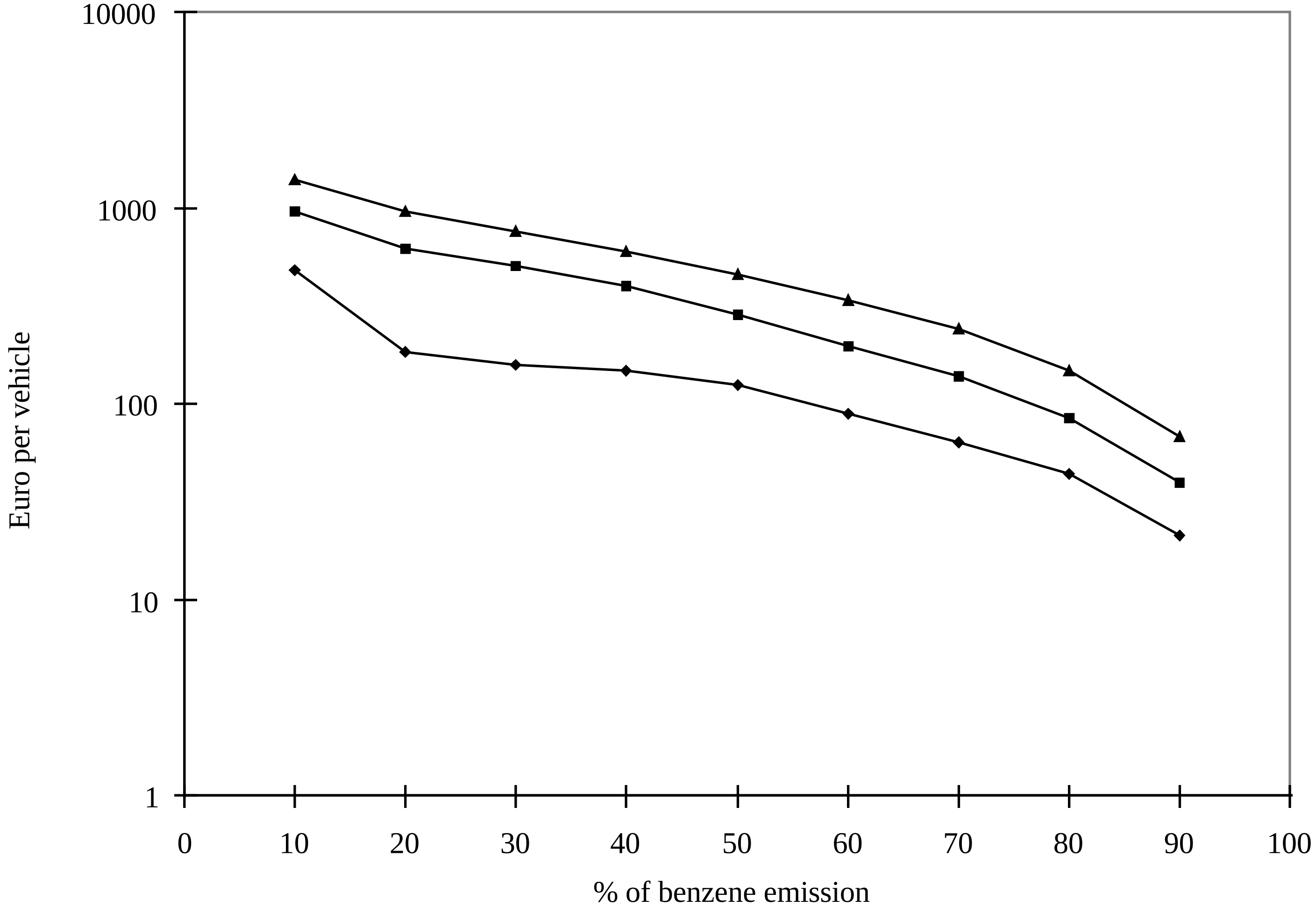


Figure 4.3. Impact of uncertainty on the cost per vehicle of technical benzene reduction measures, with 10 and 90 perrcentiles shown.

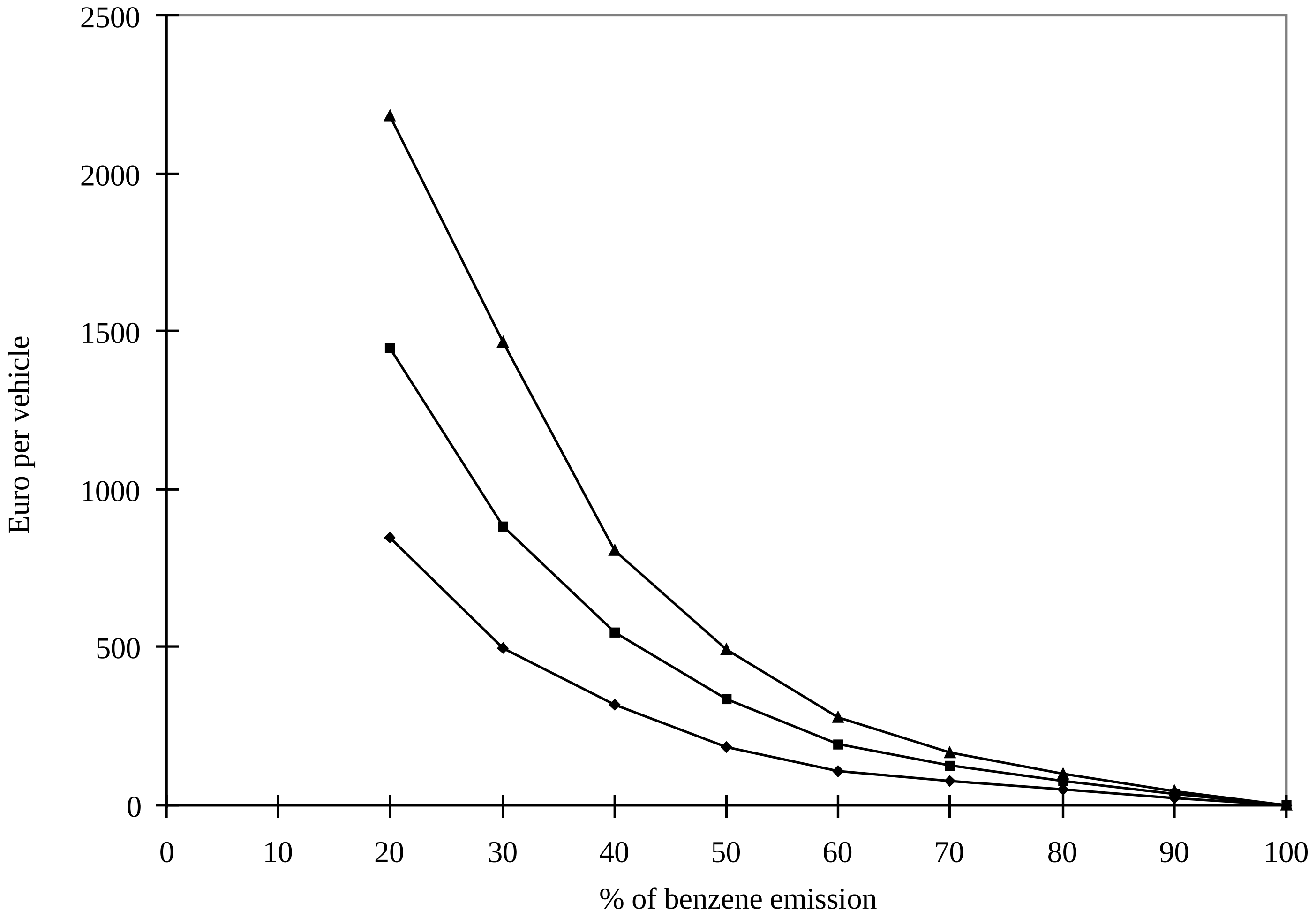


Figure 4.4. Impact of uncertainty on the cost per vehicle of CO reduction measures, with 10 and 90 perrcentiles shown.

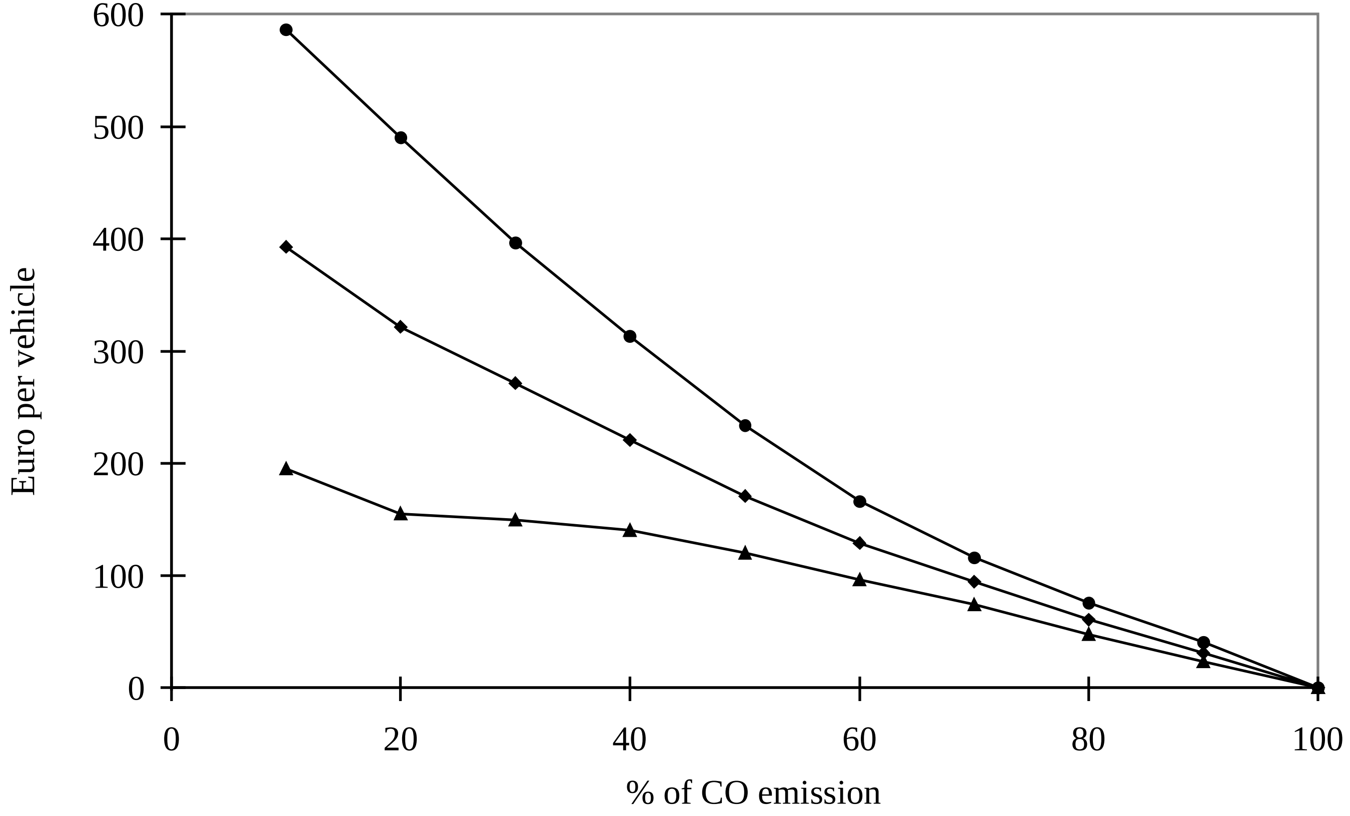
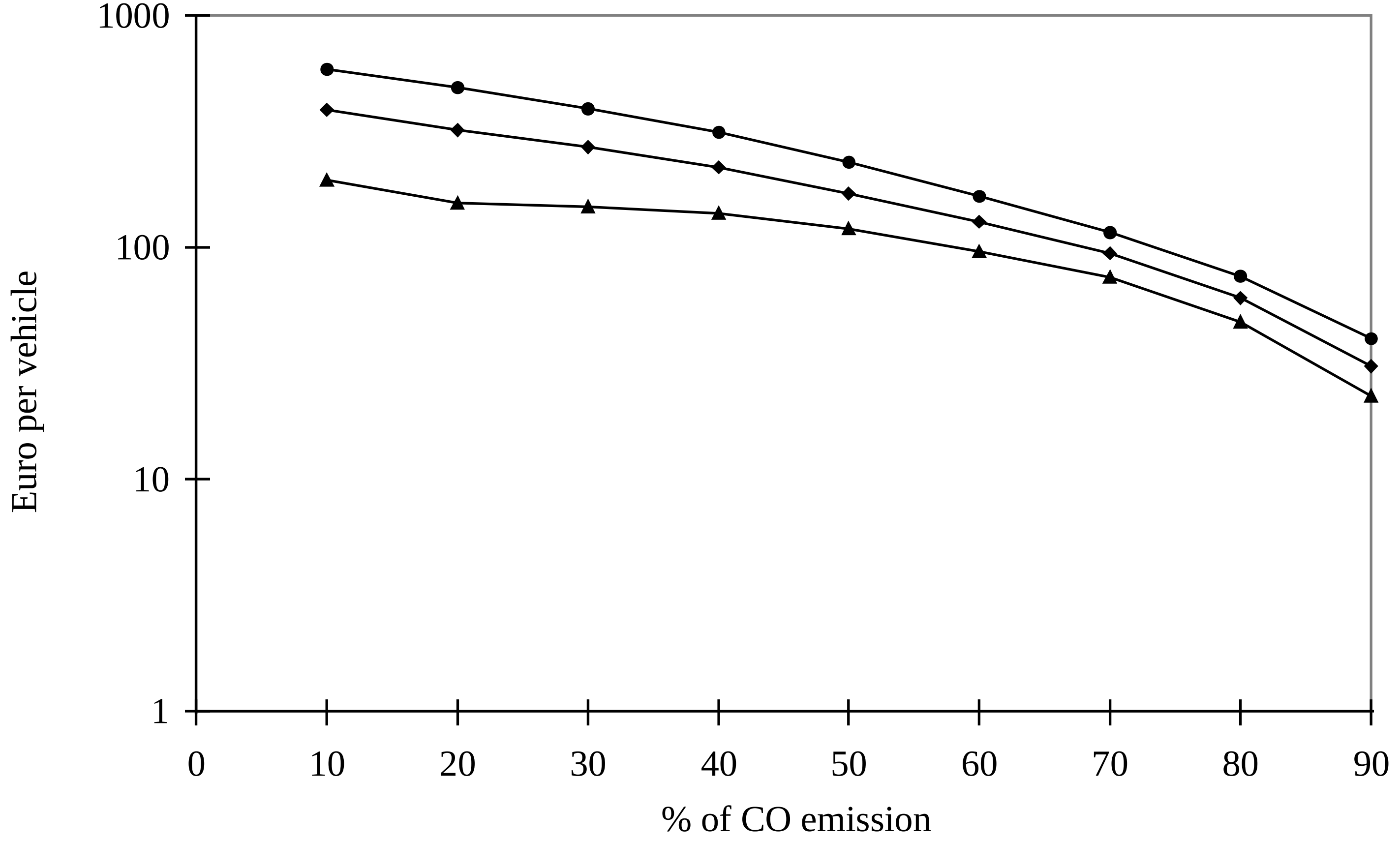


Figure 4.5 Impact of uncertainty on the cost per vehicle of CO reduction measures, with 10 and 90 perrcentiles shown.



5 Analytical Process

5.1 INTRODUCTION

This section describes how the data described in the previous chapters were brought together and what sensitivities were investigated. A list of the uncertainties identified here is given in Table 5.1. These are raised at this point to demonstrate in the remainder of this chapter the extent to which different aspects are integrated with the analysis.

Table 5.1. Uncertainties of each stage of the analysis.

Stage	Uncertainties
1. Quantification of future emissions	a) Size of vehicle fleet b) Penetration of advanced technologies c) Variation in fuel composition d) Adoption of non-technical measures to reduce congestion, etc.
2. Modelling effect of emissions on urban background pollutant levels	a) Model error b) Uncertainties in data inputs (meteorology, topography, etc.)
3. Quantification of pollutant levels in hot-spots	a) Extrapolation of monitored data between urban background and street canyon locations
4. Assessment of limit exceedences	(sum of above errors)
5. Identification of cost-effective measures for abating pollutant emissions	a) Availability of data on costs of new technological measures for pollutant abatement b) Availability of data on direct costs and secondary costs and benefits [2] of non-technical options c) Uncertainty in the rate of technological development for introduction of new technologies d) Possible error in discount rate
6. Description of exposure of the population [1]	a) Assumptions on average behaviour of the population b) Assumptions regarding the age and employment structure of the population
7. Quantification of the direct impacts of benzene	a) Extrapolation of data from studies of occupational exposures to ambient concentrations b) Assessment of the fraction of adult leukaemias that are fatal
8. Valuation of health effects	a) Possible limits of applicability of the value of statistical life, or years of life lost approaches b) Error in discount rates c) Assessment of the costs of treatment for cancers d) Extrapolation of valuation to EU level
9. Integration of secondary costs and benefits [2] of abatement options	a) Identification of secondary costs and benefits b) Quantification of associated impacts c) Quantification of associated values
10. Extrapolation from the three cities to the EU	a) Representatives of the three cities studied in detail b) Robustness of extrapolation by 1990 CO levels and population c) Sum of above errors
11. Human error	

Notes on Table 5.1.

[1] The benzene exposure-response function draws on occupational health data, requiring assumptions to be made about movement and some other aspects of personal behaviour. However, in view of the assumption that the exposure-response function is linear it is not necessary to account for smoking behaviour – see Chapter 3.

[2] The term ‘secondary benefits’ relates to all effects of the pollution abatement measures identified in this study other than the direct effects of exposure to benzene.

5.2 DETERMINATION OF AREAS OF EXCESS POLLUTION

This work has relied to a large extent so far on the large volume of data generated by AOP I. This allowed this study to take advantage of much more detailed city air quality modelling than would otherwise have been possible. In turn, this allows the resources available to this study to investigate in more detail issues such as concentrations in hot-spots and variation in population exposure, and also to undertake more sensitivity analyses. Reliance on AOP1 data means that the assumptions followed in this study should be virtually identical, with the exception of the magnitude of CO and benzene abatement between now and the target dates (2005 and 2010 respectively), given the effects of the directives that followed from AOP I.

5.2.1 Assessment of emissions and urban background levels

Data were provided on NO_x emissions in 1990 in each grid cell of a 50 x 50 (2 x 2 km) cell domain for the seven Auto Oil cities (Athens, Cologne, the Hague, London, Lyons, Madrid and Milan) (AutoOil-1, 1996). These data were disaggregated to the following source types:

- Passenger cars - gasoline
- Passenger cars - diesel
- Light delivery vehicles
- Medium and heavy delivery vehicles
- Buses
- Motorcycles
- Small stationary sources
- Medium stationary sources
- Large stationary sources

Similarly, data were provided on the concentrations of NO_x in 1990 attributable to each source in each grid cell. The Air Quality Report of AOP I (European Commission DGXI, 1996) provides conversion factors for NO_x:CO, NO_x:VOC and VOC:benzene for each city, allowing calculation of 1990 levels of CO and benzene in each grid cell of each city.

Emissions and concentrations in the future (2010) were predicted using ‘attenuation factors’ again supplied from AutoOil-1 (European Commission, 1996). These factors demonstrate how emissions of each pollutant (NO_x, CO and benzene) from each of the nine sources identified above would be reduced by the years 200 and 2010, in the absence of further action to control emissions. Further attenuation factors were calculated in this study to describe the effects of the proposed Auto Oil Directives on vehicle emissions and fuel quality, drawing on numerous sources of data (European Commission DGXI, 1996; EPEFE, undated, Touche Ross, 1995, ECDGXI, 1997a) and of the Commission’s proposals on limits for NO_x, SO_2, PM_{10} and lead (COM(97) 500 final, and IVM, 1997), for construction of the datasets for the scenarios described in Chapter 2. The effect of the

Commission's proposals on air quality for these four pollutants is more dependent on local conditions than the effect of the results of the proposed Auto Oil Directives: in cities where air quality is already predicted to meet the limits no further action will be necessary. Of the three cities studied here, likely exceedences were only estimated for Athens in the economic evaluation study undertaken by IVM (1997). To reduce concentrations to a level whereby limits would not be exceeded in Athens the IVM study found that two measures would be needed, road pricing and the use of buses running on compressed natural gas (CNG) or liquefied petroleum gas (LPG). For this study it was assumed that there would be a preference for using CNG rather than LPG, based on data from ETSU (1996), which found that the use of LPG would be likely to increase emissions of CO (Table 5.2). Use of CNG appears to have no effect on CO emissions compared to the use of diesel. It would increase emissions of hydrocarbons, though associated benzene emissions should be negligible (note that the estimate given in the Table includes methane emissions) and there would also be CO_2 savings. Road pricing was estimated by IVM to cause a 10% reduction in emissions. This was applied to all source types except buses. It is assumed here that the introduction of road pricing leads to a modal shift from private transport to buses for people travelling into cities and more efficient use of delivery vehicles.

Table 5.2. Comparison of in-use emissions from new buses running on different fuels (ETSU, 1996).

	Diesel	CNG	LPG
CO_2	885	775	864
CO	4.3	4.3	8.5
Hydrocarbons	0.4	0.7	0.9
NO_x	14.1	2.1	2.8
PM_{10}	1.1	0.16	0.3

The sensitivities identified for this part of the analysis are now described. The extent to which they were incorporated into the subsequent analysis largely reflects the wishes of the Working and Steering groups, with most emphasis being given to the assessment of benzene in hot-spots.

5.2.1.1 Sensitivity from size of vehicle fleet and penetration of advanced technologies

In the absence of further legislation or the widespread use of local measures to reduce congestion, increased size of the vehicle fleet seems inevitable. The assumptions from AOP I (EC DGXI, 1996) on traffic growth for the three cities considered in this study are shown in Table 5.3.

Table 5.3. Predicted traffic growth in Athens, Cologne and London, 1990-2010 (EC DGXI, 1996).

	City growth, %			
City	Cars	LDV/HDV	Buses	2W
Athens	+22	+15	+10	+22

Cologne	+34	+33	-1	+55
London	+15	+11	-4	+27

Change in the size of the vehicle fleet is subject to a large number of factors, and so the true figure for traffic growth may vary significantly around those shown here. These factors include economic growth, provision of substitute transport options, technological developments, stylistic developments and so on. The net effect of changes in the size of the vehicle fleet is equally complex. Increased numbers of vehicles would be expected to lead to increased congestion, lower speeds and thus more pollution. However, this could be balanced by a reduction in average vehicle age in the more affluent urban centres, particularly if there is a net outflow of older vehicles to areas with lower traffic densities.

Penetration of some advanced technologies such as vehicles powered by fuel cells could also have a significant effect. This is not accounted for here for numerous reasons, the most important relating to the price of new technologies at introduction, acceptance by consumers of new technology, date of introduction, etc. More information may be generated on this issue through the second Auto Oil Programme.

Overall, for the purpose of illustration of the effect of variation in vehicle fleets, a range of ±25% around the changes shown above is taken for the three cities. This translates to an error in prediction of benzene emissions overall of only about ±5% (25% of the mean change in fleet size). This range is not intended to take account of the effects of the potential introduction of non-technical measures to reduce congestion, which is dealt with in the cost-effectiveness analysis.

5.2.1.2 Sensitivity to variation in fuel composition

There is wide variation regarding fuel composition with respect to the content of benzene and benzene precursors. For example, Bates *et al* (1994) reported benzene (%v/v) ranging between 1.1 and 13.1%, for samples taken at a number of gasoline stations around Europe. However, the legislation developed through AOP I will reduce this variation substantially (the limit being set to 1%). A review of information given by EC DGXI (1996, 1997) suggested that a reasonable estimate of the error in the quantification of benzene emissions relative to the assumptions made on fuel quality would be likely to be of the order of 10%. Effects on benzene emissions from variation in the quality of diesel fuel are less significant and hence are not considered.

5.2.1.3 Sensitivity to modelling effect of emissions on urban background pollutant levels

One of the reasons for reliance upon the approach used under AOP I in our study is that this approach has been widely discussed by the European Commission, Member States and other interested parties. Like any modelling exercise it was inevitably prone to error. However, results appeared to tie in reasonably well with expectation. Further information may become available during AOP II. Separate account has not been taken of error in modelling procedures and inputs here.

5.2.2 Characterisation of concentrations in hot-spots

Next, calculation was made of levels in hot-spots. Simple statistical relationships were taken from available measurement data. From the APIS database (see Appendix 3) the following factors were derived from measurements made of CO concentrations in Utrecht and Athens. These were the only two cities with sites that met necessary criteria, relating to variation in traffic density, height of monitoring points, etc. There was no data on benzene in the database, but given that the main source of both is traffic it is assumed here that the proportional variation in the annual mean CO between urban background and hot-spots was similar to the variation in annual mean benzene. The statistics were as follows:

Max 8 hour concentrations (applicable to CO)	
Mean peak:urban background	3.2
Upper 95% confidence limit for peak:urban background	4.1
Highest peak:urban background	13
Annual average concentrations (applicable to benzene):	
Mean peak:urban background	3.4
Upper 95% confidence limit peak:urban background	3.9
Highest peak:urban background	7.6

Variation around these figures may be considerable. We have sought to account for the fact that emissions in hot-spots will fall more significantly than in the urban background because of the extent of emission controls on traffic, following analysis by van Eerens (1998, personal communication). Based on these additional results a multiplier of 3 was adopted for the base case and 4 for an upper bound, corresponding to the 95% confidence limit calculated above. This might be taken as representative of extreme weather conditions, which could be particularly important were the limits in the directive to be agreed with no exceedence allowed.

Further review of data has not identified other sources where the sampling intensity would appear to provide as robust an estimate of the ratio in concentrations between background and peak levels. A review of recent UK monitoring data showed little pattern in the data (Table 5.4).

The Position Paper (IIA, 1998) gives additional data for benzene levels observed in European cities in nine countries, seven of which include data for urban background and peak concentrations. These data and the respective ratios are shown in Table 5.5. The average ratio of peak to urban background concentration across all of these cities is in the range 3.2-5.0 with a mean value of 4.1, which is in good agreement with the figure identified above. More extreme results are possible - the highest ratio identified being 15.1:1. However, it is probable in such cases that the peak and urban background locations are not truly comparable - they could for example be separated by a large distance.

Table 5.4. UK benzene concentration data (1996).

Site	**Type**	**Annual mean concentration μg/m^3**	**Maximum hourly average μg/m^3**	**98th Percentile of hourly averages μg/m^3**
Belfast South	Urban background	2.9	76.5	15.2
Birmingham East	Urban background	3.2	94.3	14.6
Bristol East	Urban background	3.9	69.3	17.5
Cardiff East	Urban background	3.9	121.2	15.9
Edinburgh Medical School	Urban background	2.3	51.8	8.4
Harwell	Rural	1.3	12.3	4.9
Leeds Potternewton	Urban background	3.2	57.0	13.6
Liverpool Speke	Urban background	2.9	46.3	13.3
London Eltham	Suburban	3.6	60.6	14.9
London UCL	Roadside	6.2	84.2	20.7
Middlesborough	Urban industrial	3.2	113.4	17.8
Southampton Centre	Urban Centre	6.2	109.2	24.3

Table 5.5. Urban background and peak benzene concentrations in several European cities (IIA, 1998).

		Benzene concentration data			**Source table in position paper**
		Urban background ($\mu g/m^3$)	**Peak ($\mu g/m^3$)**	**Ratio of Peak:Urban Background**	
Basque region	Random Sampling (24h)	2.3	1.5	0.7	1-XV
	Grab sampling (instantaneous)	1.3	2.2	1.7	1-XV
Paris	Site 1: Site 2	3.0	34	11.3	1-XVII
	Site 1: Site 3	2.2	34	15.1	1-XVII
Florence	Roselli: Boboli	6	32	5.3	Fig 1-4
	Roselli: Bassi	9	32	3.6	Fig 1-4
Germany	Frankfurt (1)	4.6	13.4	2.9	1-XIV
	Frankfurt (2)	4.6	12.5	2.7	1-XIV
	Mannheim (1)	4.0	12.4	3.1	1-XIV
	Mannheim (2)	3.6	12.4	3.4	1-XIV
	Halle	3.0	9.8	3.3	1-XIV
	München	2.7-5.9	5.7-17.3	1.0-6.4	1-XIV
	Essen	2.2	7.2	3.3	1-XIV
	Berlin	2.6-3.6	5.0-13.3	1.4-5.1	1-XIV
	All cities	3.4	9.2	2.7	1-XIV
Austria	Several sites	4-7	3.7-17	0.5-4.3	1-XVII
Brussels	68 sites	1.6-11	15	1.4-9.4	1-XVII
Italy	3 cities	8	20-50	2.5-6.3	1-XVII
Germany	13 cities	2-5	10-12	2-6	1-XVII
Sweden	28 cities	2-5	7-10	1.4-5	1-XVII
Netherlands	3 cities	2-5	3-9	0.6-4.5	1-XVII
UK	6 cities	2-5	6	1.2-3	1-XVII

5.2.3 Conversion of CO levels

All data generated from the information supplied from AutoOil-1 (1996) on concentrations were given as annual averages. For CO these needed to be converted to allow consideration of the relationship with the 8-hour limit values that are under investigation in this study. The following were calculated:

- 10 mg/m^3 as the maximum 8 hour average equivalent to 1.75 mg/m^3 as annual average (from van den Hout, 1997)
- 10 mg/m^3 as the second highest 8 hour average in any year was estimated to be equivalent to 2.04 mg/m^3 as an annual average (estimated from analysis of APIS data).

To allow consideration of the scale of the problem in each city the number of grid cells in which exceedence of the limit values under investigation was detected were recorded. Required emission reductions were calculated by dividing the highest recorded exceedence by the limit value exceeded, and revised concentration maps calculated (these being used for assessment of benefits, below). To allow possible consideration of the implementation of measures at different scales according to how severe and how widespread exceedences were estimated to be, the contribution to emissions from each source type considered was calculated for:

1. the cell with highest concentration (if limits were exceeded in the scenario being considered)
2. all cells in which limits were exceeded
3. all cells in the gridded domain for scenarios where limits were exceeded.

5.3 ASSESSMENT OF THE COSTS OF MEETING THE DIRECTIVE

Cost data were reported in Chapter 4. They include data for both stationary and mobile sources, though the main concern of the study is undoubtedly the latter. The effectiveness of each measure has been estimated, allowing measures to be ranked by cost-effectiveness. These measures are then introduced until the required emission reduction is attained, taking account of the likely penetration of measures by the years 2005 (for CO) and 2010 (for benzene).

Generic cost estimates are used here as the remit of the study does not provide for the collection or analysis of site specific data. The discount rate used in this study for the private cost assessment is 7%, in line with the rate used for AOP I. It should be noted that only measures for which cost effectiveness data are available have been considered and that there are significant uncertainties associated with this data, thus the costs provided here are only a broad indication of the likely range of possible compliance costs.

Information on the costs of monitoring systems have now been collected, and need to be considered here. However, the costs of monitoring both benzene and CO are logically split between the 2nd daughter Directive and the ozone Directive, which requires monitoring of the precursors of photo-oxidants.

5.4 THE BENEFITS ANALYSIS

The impact assessment and monetary evaluation of the benefits relies to a large extent on the ExternE framework for externalities assessment developed as a collaborative effort of a number of scientific institutions, supported by DGXII. It should be noted that the ExternE methodology has advanced considerably since the series of reports published at the end of

1995. A revised methodology report on the study is due to be published shortly (European Commission, 1999). The overall framework for the benefits assessment is a logical stepwise progression from quantification of pollutant loads to valuation (Figure 5.1).

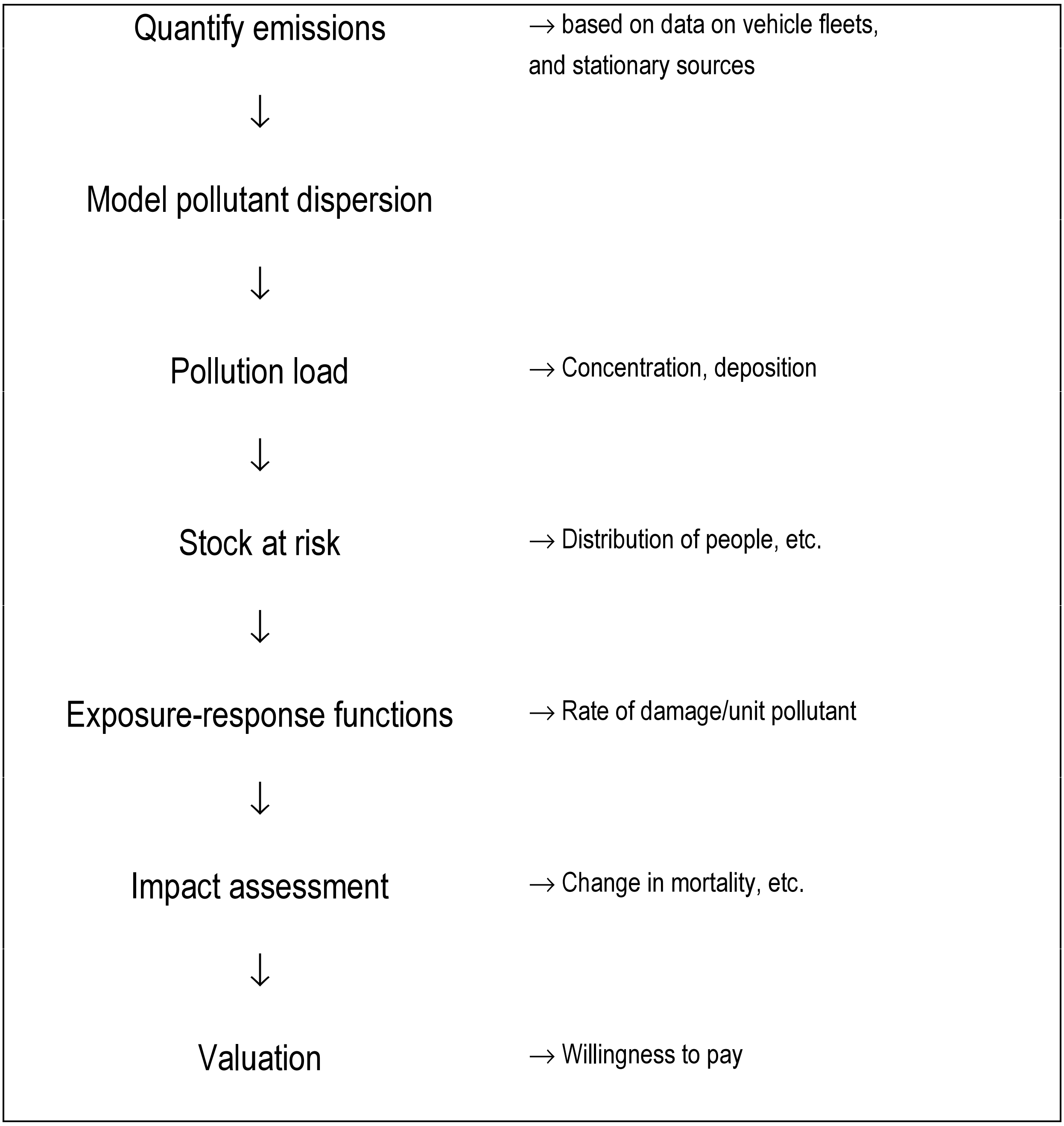


Figure 5.1. Diagrammatic representation of the impact pathway approach.

The first stage of the analysis was to map population of each city on the 2x2 km grid used for each city by Auto Oil. Population data for the three cities were taken from census records. The analysis of health effects and health costs in each cell uses a simple multiplicative approach:

[Concentration] x [population] x [risk factor] x [value per case]

From the recommendations of the ad hoc Working group convened by the Working group on Benzene, a lifetime risk factor of 5×10^{-8} to 5×10^{-6} per µg/m^3 was used. Assuming a 75 year life expectancy this converts to a range for the annual risk factor of 7.8×10^{-10} to 7.8×10^{-8} per µg/m^3. The risk shown is the estimated risk of contracting cancer, rather than the risk of dying from cancer. Separate account has not been taken of smokers and those in occupations that are associated with heightened exposure to benzene. The linear nature of the response function focuses the assessment of benefits on changes in air quality.

For valuation two situations were considered, one where all those contracting cancer die from it, and the other where only 50% die, the other 50% recovering after treatment. Given the likelihood that deaths from cancer would be likely to shorten life considerably (i.e. by a period of some years), the value of statistical life (VOSL) approach was adopted for mortality assessment. The VOSL used here is averaged over a large number of studies (see European Commission, 1995b). Converted to 1995 values provides an estimate of 3.1 MEuro for each case to which is added 250,000 Euro for cost of illness relating to cancer. This makes a total value of 3.35 MEuro per case, and is taken as an upper estimate. To give a lower estimate it was assumed that 50% of the cancers are fatal and 50% of those affected recover after treatment. This provides an average estimate of 1.8 MEuro/case.

Applied to both urban background and peak concentrations this provides a range for each scenario. This range can be refined by developing a model of lifestyle, suggesting how much time people spend in areas subject to urban background levels and in hot-spots (a model was developed above in Chapter 3). The analysis considers the benefits of a uniform reduction in emissions from each source type across the entire gridded domain, and the same uniform reduction in emissions from each source type but only in cells in which exceedences are detected. The required reduction in emissions was estimated as the ratio of highest concentration estimated in any cell divided by the limit value exceeded.

For CO the risk factors described in Chapter 3 above are taken from recent epidemiological studies. At the present time only one of these functions, for congestive heart failure (CHF), appears to be reasonably robust:
Increase in annual admissions for CHF = 5.5×10^{-7} per µg/m^3

Each case of CHF is valued at 7,870 Euro per case (European Commission, 1999), which includes both cost of illness and willingness to pay.

Two other functions for CO have been identified in the literature, for acute effects on mortality and for ischaemic heart disease. These do not appear robust at the present time (see Chapter 2), and hence were not used in our previous assessment. Mortality effects from short term exposures are considered here as part of the sensitivity analysis, with mortality valued using the value of a life year concept (see European Commission, 1999) and the value of statistical life.

There are certainly a number of issues that concern the valuation of health effects. These affect particularly the assessment of mortality and hence are especially relevant here to benzene (given that the evidence on the effects of CO regarding mortality are inconclusive).

However, compared to the potential factor 100 variation in the risk factors for benzene effects, this source of uncertainty is secondary.

Overall, therefore, it is concluded that errors in valuation of health damages are unlikely to be a major factor in this assessment.

5.5 COMPARISON OF COSTS AND BENEFITS

Costs and benefits are expressed relative to baseline scenarios. The key sensitivities in this study are likely to relate to

- the approach to the valuation of mortality, and assumptions on the fraction of adult leukaemias that lead to death
- assumptions on the relationship between urban background and hot-spot concentrations
- assumptions regarding personal exposure to benzene
- views on the reliability of published exposure-response functions for CO from epidemiological studies
- assumptions on the cost effectiveness of non-technical measures for reducing transport emissions

5.6 EXTRAPOLATION OF RESULTS TO THE PAN-EUROPEAN UNION LEVEL

The purpose of this study is to provide results that demonstrate the costs and benefits of action to control levels of CO and benzene across the European Union as a whole. The analysis described so far has however just concentrated on three cities.

There are a number of variables that may be useful for extrapolation in this case, including, but not restricted to, the following;

1. Population
2. Traffic volume
3. Emission data for CO and benzene
4. Emission data for other pollutants for which data are more widely available and which are likely to be related to emissions of CO and benzene
5. Concentrations data for CO and benzene
6. Concentration data for other pollutants for which data are more widely available and which are likely to be related to emissions of CO and benzene

Each of the variables has been assessed against a number of criteria such as the availability and comparability of data. From the list variables [1] and [5] were taken as the best indicators. [1: population] provides an index of the size of cities, and is available throughout the EU domain. Of course, in strict terms it is simply a measure of the number of people living (as opposed to living *and/or* working) in a more or less well defined area. However, it is reasonable to expect that the population of a city will also be related to its geographic area, its workforce, and the amount of traffic present. Regarding [5], measured concentration data for CO for any city reflect not only emissions but also meteorology.

Given the lack of benzene data in APIS, CO is taken as a proxy for benzene also (given the similarity in main sources).

Data showing mean CO levels over a period of 5 years from 1988 to 1992 were taken for all cities with CO data in the APIS database. For some cities not all years were available, so averages cover a shorter period of time. The period 1988 to 1992 provides a reasonably common baseline across the EU, predating the implementation of Directive 91/441/EEC that required catalytic converters to be fitted to petrol engined cars. For Germany no data were taken after 1990, recognising the earlier introduction of catalytic converters there. [Note; identical assumptions were made in AOP I (European Commission DGXI, 1996) when considering how representative the selected cities were with respect to CO levels). Combining average CO data with population gives the following profile (Figure 5.2).

The profile was split into 3 parts (A, B, and C), one for each of the three cities considered in depth in this study. Divisions are placed at the mid-points between the cities with respect to concentration. Results for each of three cities are here considered to be representative of the parts of Figure 5.2 that they come from. Accordingly, results are extrapolated to the European Union's urban population (defined as 177 million people living in cities and towns with a population in excess of 50,000) on the basis shown in Table 5.6.

Table 5.6. Data used for extrapolation of results.

	City:	Population:	Population extrapolated to:
A	Athens	3,436,000	34,000,000
B	London	6,853,000	77,000,000
C	Cologne	3,963,000	60,000,000

It will be observed that the three cities are not central to the part of the curve that they are taken to represent. The extrapolation procedure is estimated to overestimate costs and benefits by about 10%, additional to other errors in the analysis.

There are, not surprisingly, complications with using concentration data from APIS, which are taken from around the year 1990, for estimation of concentrations in 2010. The first problem concerns variation in the growth of traffic in different cities. It is notable that two of the three cities considered here, Athens and London are heavily congested and were among four of the seven Auto Oil I cities considered to be at (in the case of Milan) or close to saturation (European Commission DGXI, 1995). Data showing the ratios of projected traffic growth in the cities assessed in Auto Oil to traffic growth nationally are given in Table 5.7 (based on data from European Commission DGXI, 1995, p. 45).

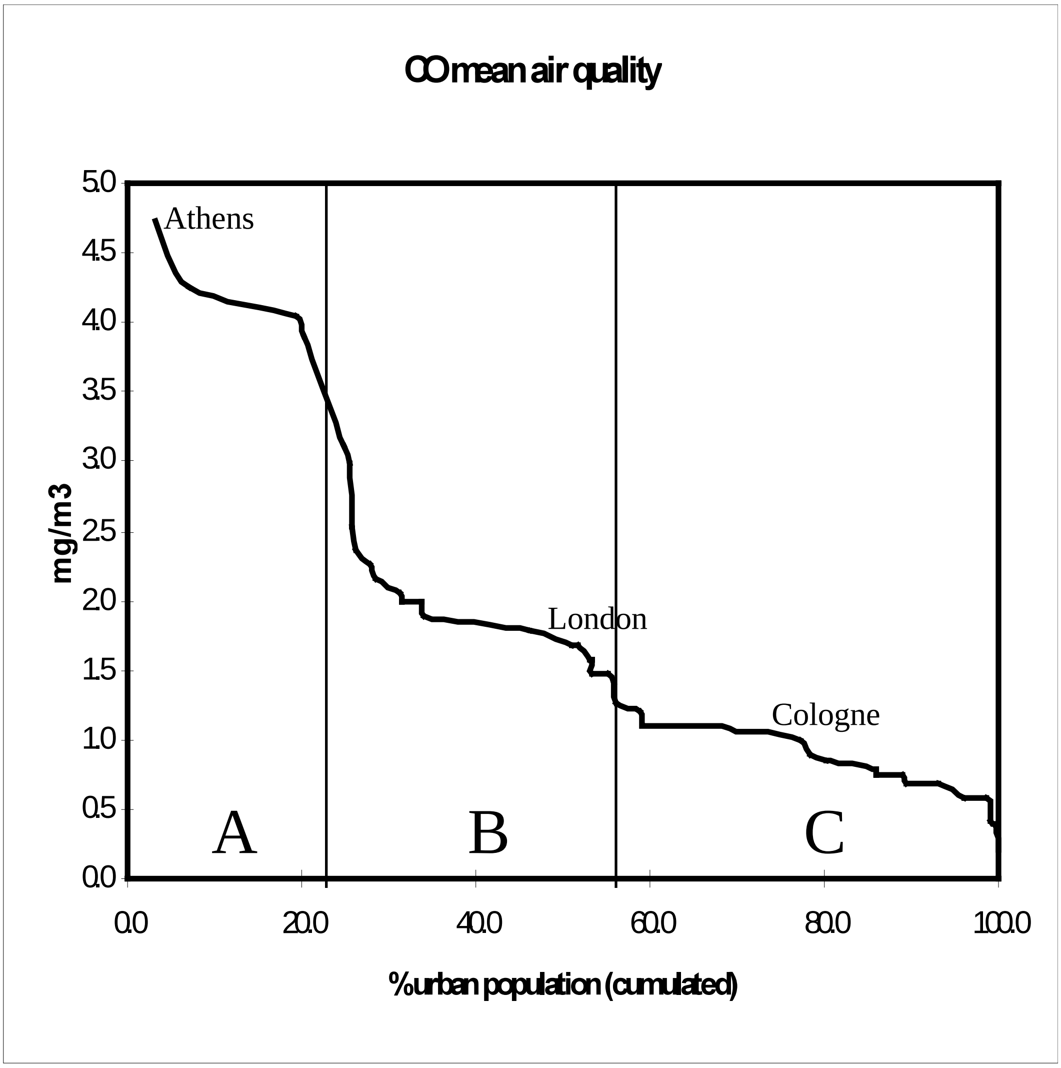


Figure 5.2. Profile of mean CO measurements in European cities against population.

Table 5.7. Mean ratios of traffic growth in the Auto Oil cities compared to national traffic growth considering four categories of vehicles; cars, light and heavy delivery vehicles, buses, and motorcycles and mopeds.

Greece/Athens	0.28
Germany/Cologne	1.00
Netherlands/The Hague	1.00
UK/London	0.36
France/Lyon	1.00
Spain/Madrid	0.31
Italy/Milan	0.00

Two of the three cities where traffic growth in cities was assumed to follow national trends have the lowest pollutant concentrations of the seven Auto Oil I cities.

5.6.1 Sensitivity in extrapolation from the three cities to the EU

In the absence of a truly robust approach for extrapolation of results from a small number of cities to the level of the EU as a whole no data are available with which to gauge the error in the method used here. The use of three cities subject to widely differing pollution problems provides a reasonable degree of protection against serious error. However, the overall uncertainty at this stage of the analysis remains a matter of speculation. Given the lack of information errors were not quantified. The problem seems more likely to affect the overall magnitude of costs and benefits rather than the ratio between them.

6 Results: CO

6.1 MAIN RESULTS

Estimated maximum concentrations of CO in Athens and London are shown in Table 6.1. Results are not shown for Cologne as no exceedences were predicted for it. The results shown are annual mean figures in μg/m^3. Exceedence of the 8 hour standards is estimated to arise when concentrations exceed 1750 μg/m^3 (10 mg/m^3 absolute limit) or 2040 μg/m^3 (10 mg/m^3 second highest 8 hour mean in any year). These are identified in Table 6.2. The 'core' estimates for hot-spots are based on best estimates of conditions, the 'upper' estimates illustrate the extent of problems that may arise through extreme meteorology.

Table 6.1. Estimated peak concentrations of CO (annual mean) in the modelled domains.

		Urban background	Hot spots	
City	Estimate		core estimate	upper estimate
Athens	Low	503	1509	2012
	Mid	591	1773	2364
	High	681	2043	2724
Cologne	Low			
	Mid			
	High			
London	Low	408	1224	1632
	Mid	480	1440	1920
	High	552	1656	2208

Table 6.2. Identification of cases where estimated concentrations exceed limit values.

		Urban background		Hot spots			
City	Estimate	10 mg/m^3 max	10 mg/m^3 2nd highest	10 mg/m^3 max core	10 mg/m^3 max upper	10 mg/m^3 2nd highest core	10 mg/m^3 2nd highest upper
Athens	Low				E		
	Mid			E	E		E
	High			E	E	E	E
Cologne	Low						
	Mid						
	High						
London	Low						
	Mid						
	High				E		E

Table 6.2 demonstrates that there will be no problems in the urban background for meeting the limits investigated. For hot-spots the problems are most severe for Athens. For

London exceedence only arises by 2005 if a high-emission scenario is followed, or if the upper estimate of the ratio from urban background to hot-spot applies (representing e.g. an extreme meteorology case).

Clarification of the extent of these problems can be gained by assessing the area over which exceedences occur and the ratio of concentration to possible limit (Tables 6.3 and 6.4).

Table 6.3. % grid cells in each domain showing exceedence.

		Urban background		Hot spots			
City	Estimate	10 mg/m^3 max	10 mg/m^3 2nd highest	10 mg/m^3 max core	10 mg/m^3 max upper	10 mg/m^3 2nd highest core	10 mg/m^3 2nd highest upper
Athens	Low				0.04		
	Mid			0.04	0.36		0.04
	High			0.96	1.36	0.64	0.96
Cologne	Low						
	Mid						
	High						
London	Low						
	Mid						
	High				1.12		0.48

Table 6.4. Ratio of concentration to possible limits where these may be exceeded.

		Urban background		Hot spots			
City	Estimate	10 mg/m^3 max	10 mg/m^3 2nd highest	10 mg/m^3 max core	10 mg/m^3 max upper	10 mg/m^3 2nd highest core	10 mg/m^3 2nd highest upper
Athens	Low				1.15		
	Mid			1.01	1.35		1.16
	High			1.17	1.56	1.001	1.33
Cologne	Low						
	Mid						
	High						
London	Low						
	Mid						
	High				1.26		1.08

In most cases the problems appear to be minor, with never more than 2% of grid cells showing any exceedence. % reductions required in some cases look high however, ranging up to 35% (Athens, high emissions estimate, 10 mg/m^3 max, upper estimate).

Table 6.5 identifies the source of emissions in the locations where the highest concentrations occur. Most of the problems in both Athens and London arise through use of petrol-engined cars (PCg). Light delivery vehicles (LDV) also make a significant contribution, particularly in Athens.

Table 6.5. Contribution to total exceedence by different types of vehicle.

CO	concentration contribution for highest concentration cell								
	PCg	**PCd**	**LDV**	**M/HDV**	**BUS**	**2W**	**SS**	**MS**	**LS**
Athens	65.65%	0.45%	18.61%	5.64%	2.91%	5.20%	1.13%	0.41%	0.00%
London	82.17%	0.60%	7.25%	5.37%	1.19%	0.00%	2.05%	0.43%	0.96%

	emission contribution for highest concentration cell								
	PCg	**PCd**	**LDV**	**M/HDV**	**BUS**	**2W**	**SS**	**MS**	**LS**
Athens	68.81%	0.46%	17.24%	5.78%	3.13%	4.20%	0.37%	0.00%	0.00%
London	81.05%	0.71%	7.64%	5.02%	1.49%	1.56%	1.93%	0.23%	0.37%

Impacts, costs and benefits are shown in Table 6.6 for Athens and Table 6.7 for London. Data are not presented for Cologne as no exceedences were predicted there. Observing that exceedences tend to be localised (Table 6.3) and at worst require a 35% reduction in emissions, it seems likely that solutions would be based on localised measures, rather than generic options that affect the entire vehicle fleet. Costs and benefits have been calculated on this basis. Mortality effects (considered as a sensitivity analysis) have been valued at a value of a life year (VOLY) of 110,000 Euro each[4].

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[4] The VOLY concept is applied to deaths linked to CO, as it is likely that the effect of CO is to shorten life expectancy by only a small amount: in other words, that the people affected are likely to be seriously ill already from other causes. The approach is discussed in greater detail by European Commission (1999). For benzene a higher valuation is applied, as the assumption made for benzene is that exposure is fundamental to the incidence of the disease (leukaemia) that causes death.

Table 6.6. Impacts, costs and benefits of the introduction of different CO limits in Athens. All benefit and cost results expressed in MEuro. 'Upper' case uses a high ratio of hot-spot to urban background, representing extreme meteorology.

Limit	**10 mg/m^3 max**	**10 mg/m^3 2nd highest**	**10 mg/m^3 max**	**10 mg/m^3 2nd highest**
Athens - low emission scenario	**Core**		**Upper**	
Cases - CHF	0	0	0.34	0
Benefits	0	0	0.0026	0
Cases - mortality - sensitivity	0	0	0.09	0
Benefits - mortality - sensitivity	0	0	0.010	0
Benefits - total sensitivity	0	0	0.012	0
Costs	0	0	0.0018	0
Athens - mid emission scenario				
Cases - CHF	0.34	0	18	0.64
Benefits	0.0026	0	0.14	0.0049
Cases - mortality - sensitivity	0.088	0	4.7	0.17
Benefits - mortality - sensitivity	0.010	0	0.52	0.018
Benefits - total sensitivity	0.013	0	0.66	0.023
Costs	0.006	0	1.93	0.016
Athens - high emission scenario				
Cases - CHF	84	43	160	102
Benefits	0.65	0.33	1.2	0.8
Cases - mortality - sensitivity	22	11	42	27
Benefits - mortality - sensitivity	2.4	1.2	4.6	2.9
Benefits - total sensitivity	3.1	1.6	5.8	3.7
Costs	20	6.6	53	25

Table 6.7. Impacts, costs and benefits of the introduction of different CO limits in London.

Limit	**10 mg/m^3 max**	**10 mg/m^3 2nd highest**	**10 mg/m^3 max**	**10 mg/m^3 2nd highest**
London - high emission scenario	**Core**		**Upper**	
Cases - CHF	0	0	116	40
Benefits	0	0	0.89	0.30
Cases - mortality - sensitivity	0	0	30	10
Benefits - mortality - sensitivity	0	0	3.3	1.1

Benefits - total sensitivity	0	0	4.2	1.4
Costs	0	0	4.4	1.2

Results are mixed, with benefits exceeding costs for some cases where only a low level of abatement is needed, and vice versa where abatement needs are higher. The analysis is considerably hampered by the lack of definitive guidance on the health effects of ambient exposures to CO.

6.2 MONITORING COSTS

The following data are based on the costs of the UK network. An automatic analyser for CO costs in the range of 9,000 to 11,000 Euro. The Local Site Operator contract would typically be around 15,000 Euro per year. Calibration gas standards would cost around 3,000 Euro per year. Running costs, including management, QA/QC, and data handling, would be in the region of 3,000 Euro per year (this is substantially less than for benzene). Thus, the estimated cost for each CO site would be in the region of 31,000 Euro for the first year, and 21,000 Euro for subsequent years.

The cost of the monitoring equipment should probably be split with the costs to be incurred under the ozone Directive for monitoring ozone precursors.

It was not possible to estimate the number of monitors required in each country as this would have required;

- information on the number of zones and agglomerations
- modelling of trends in concentrations in each zone and agglomeration.

6.3 AGGREGATION

Table 6.8 summarises the aggregated results of the study, using the methodology described in Section 5.6. It includes assessment of the sensitivity to a number of factors:

- Emission scenarios
- Relationship between urban background and hot-spot concentrations
- Inclusion/exclusion of the possible acute effects of CO on mortality.

Table 6.8 Aggregated results for CO, including sensitivity analyses. '0' is entered where there is no predicted exceedence of the indicative limit values investigated. All data in Meuro.

Limit	**Location**	**Emission scenario**	**Case**	**Benefits**	**Benefits (sensitivity)**	**Costs**
All indicative limit values	urban back	All	-	No exceedance		
10 mg/m^3 2nd highest	hot-spot	L	Core	0	0	0
		M	Core	0	0	0
		H	Core	3.2	15	65
	hot-spot	L	Upper	0	0	0
		M	Upper	0.048	0.23	0.15
		H	Upper	11	37	270
10 mg/m^3 highest	hot-spot	L	Core	0	0	0
		M	Core	0.026	0.12	0.058
		H	Core	6.4	30	200
	hot-spot	L	Upper	0.026	0.12	0.018
		M	Upper	1.4	6.4	19
		H	Upper	22	100	550

7 Results: Benzene

7.1 MAIN RESULTS

Estimated maximum concentrations of benzene in the three cities are shown in Table 7.1. The potential existence of exceedences is identified in Table 7.2. The column headed ‘upper estimate’ is not carried through to the rest of the analysis because it can be taken to represent a case of extreme meteorology. Given that the benzene limits are all expressed as annual mean figures, there should be little sensitivity to extreme weather events as these obviously will be averaged over a year. The results are given in Table 7.1 and 7.2, however, to demonstrate the level of sensitivity that exists with respect to assumptions on relationships between urban background and hot-spots.

Table 7.1. Estimated peak concentrations of benzene (annual mean) in the modelled domains.

		Urban background	**Hot spots**	
City	**Estimate**		**core estimate**	**upper estimate**
Athens	Low	2.20	6.6	8.8
	Mid	2.93	8.79	11.72
	High	3.38	10.14	13.52
Cologne	Low	1.03	3.09	4.12
	Mid	1.37	4.11	5.48
	High	1.58	4.74	6.32
London	Low	1.38	4.34	5.53
	Mid	1.84	5.52	7.36
	High	2.12	6.36	8.48

Table 7.2. Identification of cases where estimated concentrations exceed limit values.

		Urban background			**Hot spots**			
City	**Estimate**	**2 μg/m^3**	**5 μg/m^3**	**10 μg/m^3**	**2 μg/m^3 core**	**5 μg/m^3 core**	**5 μg/m^3 upper**	**10 μg/m^3 core**
Athens	Low	E			E	E	E	
	Mid	E			E	E	E	
	High	E			E	E	E	E
Cologne	Low				E			
	Mid				E		E	
	High				E		E	
London	Low				E		E	
	Mid				E	E	E	
	High	E			E	E	E	

From this analysis problems are seen to be present in the following cases;

Athens: 2 µg/m^3 - urban background and hot-spot, all emission scenarios
5 µg/m^3 - hot-spots, all emission scenarios
10 µg/m^3 - hot-spots, high emission scenario
Cologne: 2 µg/m^3 - hot-spot, all emission scenarios
5 µg/m^3 - none
10 µg/m^3 - none
London: 2 µg/m^3 - urban background high emission scenario and hot-spot, all emission scenarios
5 µg/m^3 - hot-spots, mid and high emission scenarios
10 µg/m^3 - none

To gauge the extent of these exceedences the % of the 100 x 100 km grid cell for each city subject to exceedence is now identified (Table 7.3). In most cases the exceedence is relatively small (again less than 2%) other than for the 2 µg/m^3 limit in hot spots which is widely exceeded.

Table 7.3. % grids in each domain showing exceedence.

		Urban background			Hot spots		
City	**Estimate**	**2 µg/m^3**	**5 µg/m^3**	**10 µg/m^3**	**2 µg/m^3**	**5 µg/m^3 core**	**10 µg/m^3**
Athens	Low	0.24			3.20	0.60	
	Mid	0.76			4.16	1.20	
	High	1.08			6.52	1.44	0.60
Cologne	Low				2.44		
	Mid				10.64		
	High				28.84		
London	Low				11.52		
	Mid				24.00	0.12	
	High	0.08			45.88	0.44	

Table 7.4. Ratio of concentration to possible limits where these may be exceeded.

		Urban background			Hot spots		
City	**Estimate**	**2 µg/m^3**	**5 µg/m^3**	**10 µg/m^3**	**2 µg/m^3 core**	**5 µg/m^3 core**	**10 µg/m^3 core**
Athens	Low	1.1			3.3	1.3	
	Mid	1.5			4.4	1.8	
	High	1.7			5.1	2.0	1.4
Cologne	Low				1.5		
	Mid				2.1		
	High				2.4		
London	Low				2.2		
	Mid				2.8	1.1	
	High	1.1			3.2	1.3	

The ratios shown in Figure 7.4 for the 2 µg/m^3 limit underline the extent of the problems that this option would bring about.

Table 7.5 identifies the source of emissions in the locations where the highest concentrations occur. Most of the problems arise through use of petrol-engined cars (PCg). A significant contribution is also made by light delivery vehicles and motorcycles, particularly in Athens.

Table 7.5. Contribution to total exceedence by different types of vehicle.

Benzene	**concentration contribution for highest concentration cell**						
	PCg	**PCd**	**LDV**	**M/HDV**	**BUS**	**2W**	**Stationary**
Athens	55.50%	0.41%	20.55%	4.44%	0.00%	19.10%	0.00%
Cologne	77.68%	2.85%	4.46%	4.82%	3.27%	6.92%	0.00%
London	78.02%	0.78%	11.98%	8.19%	1.03%	0.00%	0.00%

	emission contribution for highest concentration cell						
	PCg	**PCd**	**LDV**	**M/HDV**	**BUS**	**2W**	**SS**
Athens	59.60%	0.43%	19.51%	4.66%	0.00%	15.81%	0.00%
Cologne	77.68%	2.85%	4.46%	4.82%	3.27%	6.92%	0.00%
London	77.36%	1.13%	9.90%	6.01%	1.01%	4.59%	0.00%

Measures to control emissions may be taken at an extremely local level (for example at an individual road junction) or more generally (for example through adaptation to vehicle design). The extent to which each option would be used would be dependent on the extent of exceedences in both space and magnitude. The results of Tables 7.3 and 7.4 suggest that the measures taken to attain the 5 and 10 µg/m^3 limits would be localised, but that attainment of the 2 µg/m^3 in hot-spots would require more widespread action. Where widespread action is required results are presented for 2 scenarios, a generalised scenario where emissions are reduced by the ratio of the highest concentration identified to the limit value, and an optimised scenario where emissions are reduced in each cell (where necessary) such that the limit value is just reached. For the cases where only localised measures look necessary the assessment has considered only the optimised case. On this basis estimated costs and benefits of action for each of the three cities are summarised in Tables 7.6 to 7.8. Only cases where exceedences have been identified are presented.

Table 7.6. Reduced impacts, benefits, and costs arising from meeting the different limit values in Athens.

Athens **limit**	**location**	**range**	**cases low**	**cases high**	**kEuro benefit low**	**kEuro benefit high**	**kEuro cost**
2	urban back	L - opt	0.000034	0.0034	0.068	12	90
	urban back	M - opt	0.0006	0.06	1.2	213	7,260
	urban back	H – opt	0.001	0.1	2	355	20,880
2	hot-spot	L - gen	0.0027	0.27	5.4	959	454,060
	hot-spot	M - gen	0.004	0.4	8	1420	774,180
	hot-spot	H – gen	0.0048	0.48	9.6	1704	1281,880
2	hot-spot	L - opt	0.0019	0.19	3.8	675	96,180
	hot-spot	M - opt	0.0031	0.31	6.2	1101	301,270
	hot-spot	H – opt	0.0043	0.43	8.6	1527	553,530
5	hot-spot	L - opt	0.0003	0.03	0.6	107	2,460
	hot-spot	M - opt	0.001	0.1	2	355	22,820
	hot-spot	H – opt	0.0016	0.16	3.2	568	46,420
10	hot-spot	H – opt	0.0004	0.04	0.8	142	4,610

Table 7.7. Reduced impacts, benefits, and costs arising from meeting the different limit values in Cologne.

Cologne **limit**	**location**	**range**	**cases low**	**cases high**	**kEuro benefit low**	**kEuro benefit high**	**kEuro cost**
2 μg/m^3	hot-spot	L - gen	0.00089	0.089	1.8	320	135,260
	hot-spot	M - gen	0.0017	0.17	3.4	600	530,990
	hot-spot	H – gen	0.0022	0.22	4.4	780	770,060
2 μg/m^3	hot-spot	L - opt	0.000036	0.0036	0.072	13	530
	hot-spot	M - opt	0.00029	0.029	0.58	103	8,540
	hot-spot	H – opt	0.00104	0.104	2.08	369	76,200

Table 7.8. Reduced impacts, benefits, and costs arising from meeting the different limit values in London.

London							
limit	**location**	**range**	**cases low**	**cases high**	**kEuro benefit low**	**kEuro benefit high**	**kEuro cost**
2	urban back	H – opt	0.000018	0.0018	0.036	6.4	120
2	hot-spot	L - gen	0.0036	0.36	7.2	1.3	287,870
	hot-spot	M - gen	0.0059	0.59	12	2.1	655,150
	hot-spot	H – gen	0.0073	0.73	15	2.6	903,490
2	hot-spot	L - opt	0.00155	0.155	3.1	0.55	1,510
	hot-spot	M - opt	0.00369	0.369	7.4	1.3	38,330
	hot-spot	H – opt	0.0063	0.63	13	2.2	156,670
5	hot-spot	M - opt	0.000032	0.0032	0.064	0.011	60
	hot-spot	H – opt	0.00024	0.024	0.48	0.09	550

In all cases estimated benefits in terms of reducing cancers are less than the costs of controlling benzene. This is addressed again in the discussion below. The efficiency in terms of benefit/cost ratios is highest for measures targeted at reducing local exceedences, rather than at reducing emissions generally.

7.2 MONITORING COSTS

The following data are based on the costs of the UK network. An automatic analyser for benzene, or benzene, toluene and xylene, costs in the range of 26,000 Euro to 37,000 Euro. A Local Site Operator would be needed to take care of the sampler, and a typical contract for this would be around 15,000 Euro per year. Calibration gas standards would cost around 3,000 Euro per year and electricity and nitrogen cylinders in total around 750 Euro per year. Running costs, including management, QA/QC, and data handling, would be in the range of 15,000 to 22,500 Euro per year. Thus, the estimated cost for each benzene site would be in the region of 60,000 - 78,000 Euro for the first year, and 34,000 - 41,000 Euro for subsequent years. The cost of the monitoring equipment should probably be split with the costs to be incurred under the ozone Directive for monitoring ozone precursors.

It was not possible to estimate the number of monitors required in each country as this would have required:

- information on the number of zones and agglomerations
- modelling of trends in concentrations in each zone and agglomeration.

7.3 BENZENE LEVELS AROUND SERVICE STATIONS

Specific modelling of benzene concentrations around service stations and other facilities for transferring fuel has not been conducted as part of this study. However, reports provided by CONCAWE provide details of two measurement campaigns. The first investigated short term (24 hour) concentrations around service stations and distribution terminals in 10 countries across European (Bates *et al*, 1994). The second provided measurements over a one year period in and around a single service station in the United Kingdom (Lewis and Simpson, 1996).

The Bates *et al* study revealed the possibility for extremely high concentrations to exist around service stations, with the highest 24 hour level registered being 119 $\mu g/m^3$ for a site in Greece in winter. Fuel benzene concentration at this station ranged from 2.5 to 3% v/v; conditions for the period appear to have been anti-cyclonic, with wind speeds of 1 m/s or less. Another factor apparent from Bates *et al* is a high degree of variability in the results with results for some locations being similar to background levels. Unfortunately inspection of the data showed that there was little pattern in the results when compared to fuel benzene content (which ranged from 1.1 to 13.1% v/v), fuel throughput (3890 to 22890 l/day) or temperature. Extrapolation of the results does not therefore look possible.

Only 2 of the service stations in the study, both in Sweden, were equipped with Stage II vapour recovery systems. Concentrations of benzene in the 'traffic and forecourt' location that gave some of the highest readings generally, suggest (as expected) that the vapour recovery systems were effective in lowering benzene concentrations. However, as the fuel samples for these 2 sites were lost in transit no real indication of the effectiveness of the vapour recovery system is possible.

Lewis and Simpson (1996) used active and diffusive sampling techniques around a single service station in the UK for a period of one year. The mean concentration of benzene in the gasoline sold at the site was 0.94%. Total gasoline sales over the year were 2.85 million litres. This is medium in size compared to the stations listed by Bates *et al*, though average daily throughput was only about one third of that at the largest service station (in terms of fuel sales) considered by Bates *et al*. Results showed annual mean concentrations of between 1.6 and 6.9 $\mu g/m^3$, with an average of 3.8 ug/m^3. Service station activities were found to contribute 65% (2.4 $\mu g/m^3$) of this, an adjacent road another 15% leaving 20% attributed to background. The service station was not equipped with vapour recovery facilities.

The results of the CONCAWE studies suggest that problems in meeting the air quality limits for benzene being considered in this study (annual averages between 2 and 10 $\mu g/m^3$) may well exist around service stations. The most appropriate technique for dealing with this problem would be the use of Stage II vapour recovery equipment. As shown elsewhere in this report the effectiveness of this technology in reducing emissions is around 63%. This rate of recovery may not to be sufficient to reduce benzene levels to the limits considered here. Costs per tonne of benzene emission avoided are in the range 27,000 to 120,000 Euro. The use of vapour recovery for reducing VOC emissions is already underway in a number of EU Member States. All service stations in Austria, Denmark, Germany, Italy, the Netherlands and Sweden are required to be fitted with Stage II systems by the year 2000. The costs and benefits of any directive enforcing the use of vapour recovery would thus be zero, for these countries at least. There is interest elsewhere in the European Union, as shown by studies underway in Finland, Greece and the UK. Some petrol station owners appear to be making voluntary moves to introduce Stage II.

There are 2 drivers for action to reduce VOC emissions from service stations. One undoubtedly is concern over the health effects of VOCs, though there seems to be more concern over the effects of VOCs on tropospheric ozone levels. Given this, and the fact that vapour recovery is also considered in ongoing work on the EU strategy for dealing with ozone (and hence could be double counted here), specific analysis of vapour recovery's costs and benefits with respect to benzene has not so far been attempted within this study. Additional modelling work would be possible, if it was thought to be a priority for the remainder of the study.

In summary there is certainly cause for concern that concentrations of benzene in and around service stations might exceed the possible limit values being considered here. Short term concentrations in excess of 100 $\mu g/m^3$ have been recorded in measurement campaigns run by CONCAWE. The most effective control of these emissions is likely to be through the use of Stage II vapour recovery systems, which are already being adopted in a growing number of EU Member States, and may become mandatory elsewhere in order to meet the demands of the proposed Emission Ceilings Directive.

7.4 AGGREGATION

The aggregation procedure was described above in section 5.6. Results for benzene are shown in Table 7.9. The column headed 'impacts' shows total cancers, not fatalities. No account is taken of monitoring costs here.

Cells with 0 entered represent cases where no exceedence is predicted.

Table 7.9. Aggregated results of the analysis for benzene, estimating costs and benefits throughout the EU. Cells with 0 entered represent cases where no exceedence is predicted.

Limit			Impacts (cases)		Benefits (kEuro)		Costs (kEuro)
µg/m³	Location	Emissions	Low	High	Low	High	
2	urban back	L - opt	0.0003	0.034	0.67	119	890
		M - opt	0.0059	0.59	12	2,107	71,800
		H – opt	0.010	1.0	20	3,583	207,850
2	hot spot	L - gen	0.081	8.1	162	14,344	9,774,150
		M - gen	0.13	13	265	23,151	23,059,710
		H – gen	0.16	16	330	28,691	34,491,730
2	hot spot	L - opt	0.037	3.7	74	6,879	976,220
		M - opt	0.077	7.7	153	12,463	3,539,690
		H – opt	0.13	13	263	20,713	8,389,050
5	urban back	L - opt	0	0	0	0	0
		M - opt	0	0	0	0	0
		H – opt	0	0	0	0	0
5	hot spot	L - opt	0.0030	0.30	5.9	1,058	24,330
		M - opt	0.010	1.0	20	3,511	226,360
		H – opt	0.019	1.9	37	5,619	465,280
10	urban back	L - opt	0	0	0	0	0
		M - opt	0	0	0	0	0
		H – opt	0	0	0	0	0
10	hot spot	L - opt	0	0	0	0	0
		M - opt	0	0	0	0	0
		H – opt	0.0040	0.40	7.9	1,404	45,590

8 Conclusions

The following conclusions are drawn from this study:

1. The main source of CO and benzene in areas where concentrations may be of concern is the transport sector, and passenger cars running on gasoline in particular. This will remain the case even after the Auto Oil Directives on fuel quality and vehicle emissions come into force.

2. Inclusion of new data to this final report has significantly altered the results, with the general effect of making limit values more easily attainable.

3. There is limited knowledge of the effects of CO on human health. Available epidemiological data suggest that it may be more harmful than originally thought, though these data are limited and need further investigation.

4. Although benzene is a known carcinogen its effects at ambient levels are uncertain, though from the results of this study would appear to be small. As is common practice this study has relied upon extrapolation of data from analysis of occupational exposures. The problems of doing this are underlined by the factor 100 variation in the risk factor, as recommended by the ad hoc meeting of experts convened under the working group.

5. Under current and proposed legislation, in some cities (e.g. Cologne) there is unlikely to be exceedence of the limit values investigated for CO, or of the less strict limits investigated for benzene. In others (e.g. Athens) there is likely to be significant exceedence, particularly in areas where emissions are high ('hot-spots').

6. In most cases where exceedence exists it looks unlikely that further abatement of benzene or CO specifically would be justifiable on cost-benefit grounds according to current knowledge, without bringing in a number of secondary benefits. To do this could compromise the cost-benefit comparison, leading to recommendation of sub-optimal measures for control of the secondary benefits.

7. However, it is noted that in many cases the exceedences detected are extremely localised and would not require a major reduction in CO or benzene emissions. This may be achieved in the future through the application of measures to control other traffic-related problems. A good example would be increased fuel efficiency of vehicles, which is currently under discussion. It may even be achieved through measures needed to control the pollutants covered under the first daughter Directive - current evidence suggests that these will need to be more stringent than the measures identified in the earlier IVM (1997) study, which was used here in formulation of the baseline scenario.

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