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Urban Energy-Use: Guidance on Reducing Environmental Impacts

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Executive Summary

Energy related emissions from industry, transport and the domestic sectors are the dominant cause of poor air quality in urban areas. This study has reviewed the environmental effects of these emissions and concludes that they are extremely important.

Energy related air pollution is responsible for major health problems in the local population through the cause or exacerbation of respiratory disease. It damages buildings, and affects local amenity through visibility and odour. Urban air pollution also has wider effects away from the source of emissions, damaging the natural environment, agriculture, forestry and freshwater fisheries. This study reviews the approaches for quantifying impact and their economic damages and draws conclusions on appropriate methodologies, based on the approaches being used widely in the UK, Europe more widely the International literature to inform the development of environmental policy.

The study has also reviewed the literature concerning air quality impacts on poor and vulnerable groups. Of course, for people living in poverty the most pressing priority is the satisfaction of the basic human needs such as shelter, availability of potable water, sanitation, etc. However, the review shows that the poor tend to suffer from the effects of air pollution dis-proportionately, and that poor air quality itself actually exacerbates poverty. A particular issue identified concerns the indoor air pollution from the use of solid fuels for domestic energy. The resulting health impacts dominate effects on the urban poor. Given these effects, we conclude that air pollution measures that aim to address energy use for the poor are likely to have very large benefits in reducing the health and economic impacts on these groups.

The final area of the study presents guidance on how measures for reducing energy-related pollution can be assessed and prioritised. The use of the approaches identified for assessing the environmental impacts and economic effects of air pollution are recommended for use in air quality management, as these provide a more balanced approach for prioritising measures. The guidance allows consideration of multi-pollutant issues: it can provide information on the specific environmental benefits of different options, and it allows overall consideration of benefits across different sources, pollutants and categories of effect.

The study has also identified a number of categories of effect that are often excluded in assessing air quality improvement options and suggested ways that these could be incorporated. The first of these relates to climate change and the potential conflicts between local air quality and global climate. It is suggested that the potential effects of climate change are included in the analysis of local air quality measures, so as to give higher priority to measures to improve local air quality that have low carbon emissions. We also highlight that the reverse applies to the assessment of mitigation measures for carbon abatement (for example as relates to clean development mechanisms). This area is highlighted as one that warrants further research as a priority.

The second area relates to socio-economic and equity considerations. As well as assessing the costs and effectiveness of measures, options need to be assessed and prioritised for their potential social or economic impacts/benefits, especially in relation to poorer or more vulnerable groups. By considering such aspects alongside other criteria, air quality management can give higher priority to measures that have positive poverty alleviation

aspects. However, it is stressed that assessing the short-term and long-term distributive impacts of options and projects, particularly on low-income groups, is difficult. Further research is warranted to identify ways of presenting these potential impacts as an adjunct to conventional cost-benefit assessment, for example through weighting systems or stakeholder analysis.

The overall approach and framework has been tested with case studies in China and the Republic of South Africa. These have investigated the relevant issues, data availability and practical effectiveness for specific areas. The case study in China has demonstrated the approach to quantification and shows how important these effects are in environmental and economic terms in developing countries. The study in the RSA has paid particular attention to assessing the balance of local air quality improvements, climate change effects and equity.

A number of research priorities have been identified from the study. These are:

- Further work to develop methods for quantifying the health effects of indoor air pollution.
- International co-operation and co-ordination to help agree the methods described for ambient air pollution, to agree protocols for dealing with uncertainty, and to tackle the issues of transferring economic values (and also a number of impacts such as the chronic health effects) from developed to developing countries (to avoid Western bias).
- Further investigation of the potential synergies and conflicts between local air quality improvements and greenhouse gas emissions.
- The incorporation of equity issues within existing frameworks for assessing options.

Taken together, it is hoped that the guidance here can help in drive the selection, implementation and prioritisation of measures which achieve most environmental benefits (by targeting most important pollutants and sources) and which are appropriate, cost-effective, equitable and locally and globally sustainable.

Contents

Appendices

1 Introduction

Energy related emissions arising from industry, transport and the domestic sectors are typically the dominant cause of poor air quality in urban areas, though different sectors lead to differing problems and risks. Improvement of air quality, whilst also improving access to energy services and improving overall quality of life, is therefore one of the major challenges for developing countries.

Poor air quality contributes to numerous environmental impacts. Pollution is responsible for major health problems in the local population through the cause or exacerbation of respiratory disease, it damages buildings, and affects local amenity through visibility and odour. Urban air pollution also has wider effects away from the source of emissions, damaging the natural environment, agriculture, forestry and freshwater fisheries.

Poor air quality also has a strong correlation with poverty. Less affluent districts tend to be concentrated in areas with a higher density of roads, traffic and industry. Problems are often further exacerbated from the use of poor quality fuel for domestic energy supply. The pollution in these areas adds to existing problems such as poor diet and health care access, with vulnerable groups most at risk. Indeed, studies have shown that the incidence of respiratory disease amongst children in the urban areas of developing countries is orders of magnitude higher than in Western Europe. The families in these areas can least afford the economic impacts of air pollution – such as the money to pay for treatment or the loss of earnings through pollution related illnesses.

Reducing the impact of urban energy use is therefore a key aspect in the development process. However, it is necessary to target resources towards the most efficient ways of improving air quality.

This DFID funded Knowledge and Research project (R7369 - Urban Energy-Use: Guidance on Reducing Environmental Impacts) has set out to provide guidance on how to target resources by assessing the costs and benefits of different air quality improvement measures. This document, the final report from the study, details the results and finding of the study.

Chapter 1 reviews urban energy-related emissions and effects. It details the energy-related sources of pollution, the health and environmental impacts, and the economic costs of these impacts. It also makes conclusions about which pollutants and effects are of most concern in the urban environment.

Chapter 2 reviews the evidence linking poor air quality with poverty and vulnerable groups.

Chapter 3 reviews the measures for reducing air quality problems in developing countries and details how their cost-effectiveness can be assessed. It also describes how this information, together with the information on external costs can be combined in air quality management and strategy.

Chapter 4 brings together the work in the conclusions of the study. It summarises the guidance on prioritisation and effectiveness (in terms of costs and benefits) of measures for improving urban air quality within urban areas, with particular targeting of poor vulnerable groups, so as to achieve the greatest improvements in health and environment in the most effective way.

Appendix 1 and 2 present the results of the case studies, undertaken in China and the Republic of South Africa. Both studies show the application of the recommended approach, report on lessons from potential introduction of different measures in selected countries, and discuss local specific issues and evidence.

Appendix 3 presents output from one of the dissemination activities undertaken in the project – a question and answer session conducted during an International course convened by the IAEA involving participants from Asian countries[1].

In preparing this final report, it is important to note there is an extensive body of literature in this area, though there is by no means a consensus on the issues and approaches that should be used. In order to provide review information in a clear and concise approach, and to let the reader know where authoritative sources of information (with more detail) can be found, the document provides interactive Internet links. This allows the reader to readily access more detailed information from the electronic version of this word document (just by clicking with the right hand mouse button). As well as keeping this document manageable, it is hoped that this will allow the user to be able to access the most up-to-date information.

[1] China, Mongolia, Indonesia, India, Pakistan, Thailand, Bangladesh, Sri Lanka, Nepal, and the Phillipines.

2 The Environmental Impacts and Costs of Energy Use in Urban Areas

2.1 Introduction

This Chapter presents a brief review of urban energy-related emissions and their environmental effects. As well as assessing the importance of individual pollutants and sources, this section assesses the health and environmental effects in terms of impacts and in terms of their economic effects, commonly known as external costs.

2.2 Urban Energy Use in Developing Countries

Over the past few decades urban energy use and related emissions have increased dramatically in developing countries. These increases have occurred as a result of rapid urbanisation and also because of increasing socio-economic development and the embedded links that tie it to energy demand. These increases in energy–related emissions have in turn lead to the deterioration of urban air quality throughout the cities of the developing world.

Trends in urbanisation are forecast to continue in developing countries: current rates are more than 6 percent per annum, broadly equivalent to a doubling in the urban population every 12 years (World Bank, 2000). Urban energy-use is also predicted to increase. In 1990 developing countries consumed about ¼ of global commercial energy. By 2030 this share is expected to increase to more than two-thirds (Angelson, 1997). This will be centred in certain geographical areas - energy use is predicted to increase by 100% in Asia and the Pacific and by as much as 80% in Latin America over the period 1990 – 2010.

These energy trends are forecast to continue. Unless the links between economic development and energy use can be broken, or cleaner energy use encouraged, then urban air quality in developing countries will decline further.

2.3 Urban Energy Related Sources of Air Pollution

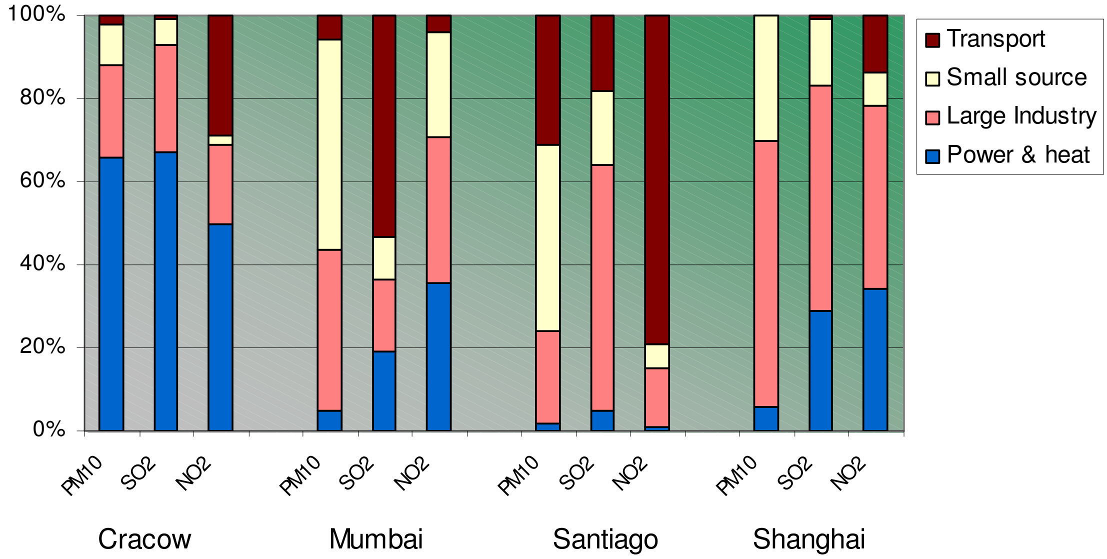
Urban energy-use in developing countries is dominated by fossil fuels. The main fuel sources are coal, oil, natural gas, town gas, coke, lignite, heavy fuel oil, petrol and diesel. For all these fuels, combustion results in a number of common emissions, namely:

- SO_2;
- NO_x;
- CO;
- Particles (PM_{10});
- CO_2;
- Hydrocarbons (methane and non-methane volatile organic compounds [nmVOCs] including potential carcinogens such as benzene).

There are also some additional pollutants from specific fuels or sectors (e.g. lead emissions from petrol vehicles), which vary with sector and associated fuel type.

The emissions from urban energy use result in changes in air quality concentrations, both in the immediate area of the emission source and across a larger area as pollutants are dispersed. In general, higher emissions will mean higher air pollution concentrations. However, the links between emissions and pollution concentrations are complicated by a number of other factors.

Firstly, in any urban area, there will be other sources of air pollutants. These can arise from non-energy related emissions, e.g. particle concentrations will be affect by road dust or wind-blown dust. They can also arise from regional transport of pollutants from neighbouring cities or areas. Secondly, the nature of the emission source can dictate how important it is in terms of affecting air pollution concentrations. Emissions that are released at ground level, such as transport and typical domestic or small industrial sources, can have a disproportionately large effect on local air quality, as they are typically released at ground level in the central areas of cities. In contrast, power generation and larger industrial emissions are generally released from tall stacks. In some areas these larger plants are located on sites at the edge or just outside urban areas that further reduces their effects. These factors are the reasons for the difference between emissions and air pollution concentrations in the Figure below (World Bank, 1997b).



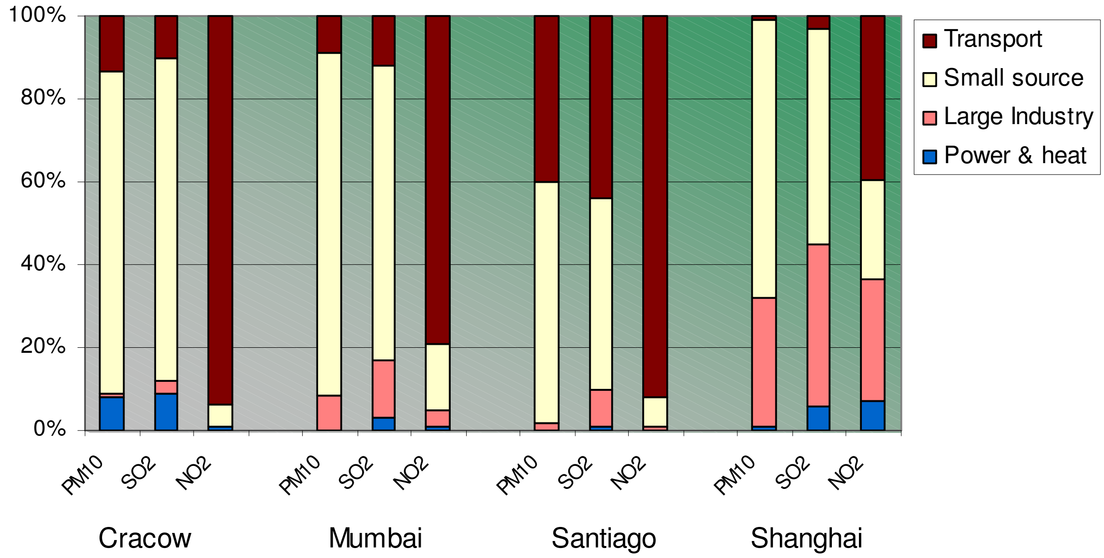


Figure 1. Contribution to Emissions (top) and Ambient Air Concentrations (bottom) from Fuel Combustion by Sector.

The figure clearly shows the greater importance of transport and small sources, as evident from the percentage contribution to air quality levels. Such effects are extremely important when looking to improve urban air quality; reducing the emissions from different sources may lead to very different improvements in air quality. Moreover, greater potential benefits may be achieved by tackling certain air pollution sources as a priority.

In addition to the direct emissions from combustion, the pollutants emitted from energy-use are also involved in the formation of other pollutants, as a result of chemical transformation or reaction in the atmosphere, known as secondary pollutants. These include ozone (formed from NO_x and VOCs in a photochemical reaction) and secondary particulates and acidic deposition (formed from SO_2 and/or NO_x). These secondary pollutants are also important in air quality, though many of their impacts occur at a regional level, rather than in the immediate local environment.

2.4 Air Quality in Developing Countries

Air quality data in world mega-cities cities is monitored by the World Health Organisation (WHO)/United Nations Environmental Programme (UNEP) under it's Global Environment Monitoring System (GEMS/Air) (http://www.who.int/peh/air/gemsair.htm)[2]. This programme assesses urban air pollution, air quality management and assessment capabilities in more than 20 major cities around the world. In general, air quality is poorest in the cities of developing countries.

Interestingly, the balance of pollutants do differ by region: SO_2 is especially high in Chinese cities, because of high coal use, which often has a high sulphur content. High NO_x levels are found in those cities with high volumes of car traffic, such as south-east Asia. Where these emissions are released in sunny areas they can also lead to ozone formation through photochemical reactions.

In all cases, poor air quality results in a number of health and environmental impacts. Although these also occur in European and US cities, the extremely high levels of air pollution concentrations in the urban areas of developing countries, makes them of particular concern.

There is one other issue that is especially relevant in developing countries – that of indoor air pollution. The use of coal or other solid fuels for domestic energy supply can lead to very high levels of pollutants in areas where families spend a large proportion of their time and in turn to exposure levels many times that of outdoor air pollution.

[2] The programme GEMS/AIR was a global programme for urban air quality management operated jointly by WHO and the United Nations Environment Programme UNEP from 1975 to 1996. GEMS/AIR was a component of the United Nations Environment Monitoring System (GEMS) which is a component of the UN Earth-watch System. Technical collaboration with developing countries was a main focus of the programme from the very beginning by providing those countries with monitoring devices. The GEMS/AIR information products also include relevant city air quality trends and air quality management and assessment capabilities in 20 major cities.

2.5 The Environmental Impacts of Air Pollution

The main environmental impacts from energy-related air pollution are:

- Effects on human health;
- Effects on the man-made environment (e.g. buildings, materials, crops);
- Effects on the natural environment (e.g. forests, natural ecosystems);
- Effects on amenity (e.g. visibility, odour).
- Potential climate change effects through greenhouse gas emissions;

These air pollution impacts can occur from primary and secondary pollutants, and may impact at both a local and a regional scale. Primary pollutants are emitted directly by the process of combustion – secondary pollutants are formed reactions between primary emissions in the atmosphere, for example, with the formation of ozone from NO_x and VOC emission in the presence of sunlight, or from formation of acidic species from NO_x and SO_2 emissions. A brief review of the main effects and pollutants involved are described below.

2.5.1 Air Pollution and Health

Studies of pollution episodes, such as the London smogs of the 1950s, have shown that very high levels of ambient air pollution are associated with strong increases in adverse health effects. Recent studies also reveal smaller increases in adverse health effects at the current levels of ambient air pollution typically present in urban areas in counties like the UK despite the extensive environmental legislation introduced since the 1950s. These health effects include a range of endpoints, such as premature mortality (deaths brought forward), respiratory and cardio-vascular hospital admissions, and possibly exacerbation of asthma, other respiratory symptoms and loss of lung function.

The evidence for these effects is strongest for the pollutants PM_{10} , SO_2 and ozone and the relationships are widely accepted as causal. Recent studies also suggest that long-term (chronic) exposure to these pollutants, especially particles, may also damage health and that these effects may be substantially greater than the acute effects described above. There are also potential effects from carcinogenic pollutants, such as benzene, which are also emitted from fuel combustion, and for specific compounds such as lead.

Most of the evidence for these effects are based on studies in the US and EC. However, the evidence that they also apply in developing countries is increasing. Indeed, it is likely that these effects are even greater for such countries due to the very high pollution levels. Epidemiological studies showing associations between pollutants and acute health effects have now been undertaken in a number of the more polluted developing country cities (e.g. Beijing, Shenyang, Jarkarta, Santiago, Mexico city and an increasing number) and show similar health impacts as for Western countries.

2.5.2 Air Pollution and Materials

The effects of atmospheric pollutants on buildings provide some of the clearest examples of air pollution damage. Impacts fall into two main categories: material erosion/corrosion and soiling.

Soiling results primarily from the deposition of particles on external surfaces and discolouration of stone and other materials including glass. It is one of the most obvious signs of pollution in urban areas.

Erosion results from the effects of acidic deposition. For most materials, the dry deposition of SO_2 exerts the strongest corrosive effect of atmospheric pollutants. Wet deposition (rain acidity - a secondary pollutant formed from SO_2 and NO_x emissions) has a weaker corrosive effect. NO_x and VOCs also have a role in material damage, through the formation of ozone, which is known to damage polymeric materials such as plastics and rubbers.

Although impacts on buildings are of less concern than basic quality of life issues and health, sanitation, etc. they are still a real urban impact, especially at the levels of air pollution in developing countries. These effects occur at the local level within the urban area and at the regional level through acidic deposition.

2.5.3 Air Pollution and Crops and Ecosystems

Air pollution also effects crops, with ozone being regarded as the main pollutant of concern, at least in Europe and the US. Ozone has harmful effects on many plants at the concentrations commonly found and leads to reduced crop yields. A large number of other atmospheric pollutants have also been found to influence crop yield or quality, such as SO_2, NO_x and acidic deposition,), though these are often masked by normal agricultural practice and complicated by other interactions. SO_2 is more important in developing countries when very high levels of deposition occur. In all cases, reduction in crop yield from regional pollution from urban emissions is an important issue given the availability and price of food in the cities of developing countries. Impacts on ecosystems ranging from forests to freshwater are also well documented. Acidity and nutrient supply (nitrogen deposition) are both powerful factors in determining species distribution and ozone also has important effects on species richness. These effects, which arise from regional pollution and deposition, are extremely important with respect to bio-diversity and ecosystems. Examples of the types of forest damage seen in Europe in previous decades are already occurring in areas of high coal use, such as China, such as in forests and sensitive ecosystems (e.g. high alpine tundra in Tibet).

2.5.4 Climate Change

The impacts of climate change (global warming) are diverse and potentially very large. They include effects on all of the receptors affected above. There is reason to believe that the effects of global climate change are the most serious of all impacts. However, analysis of the effects of global warming is complicated by a variety of factors including the long time scales involved, the global nature of impacts and uncertainty concerning the extent of global temperature increase and its effect on regional climate. The main pollutants of concern (greenhouse gases) are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), though other pollutants can contribute indirectly.

2.6 Quantifying the Environmental Effects of Air Pollution

Major advances over recent years now mean it is possible to assess the health and environmental effects of air pollution. For urban air pollution, the steps for quantification are:

- To quantify the emissions from the pollutant source;

- To assess the impact on air pollution concentrations in the surrounding area from these emissions (using air pollution dispersion models);
- To assess the population or receptors exposed to these pollution increases;
- To use exposure-response functions that link pollution increments to health or damage endpoints.

There is an additional final step that can be undertaken: to convert the environmental effects into economic units. This step is discussed in more detail in a later section.

This step by step approach is known as a bottom-up or impact pathway approach and is summarised in the figure below. The impact pathway simply relates to a sequence of events linking a burden (such as an emission) to an impact, quantified in physical terms. The methodology therefore proceeds sequentially through the pathway. It provides a logical and transparent way of quantifying externalities. However, only recently, through developments in environmental science and economics, has it become a realistic proposition. The approach has been used in studies such as the EC's ExternE project (http://ExternE.jrc.es/), which provides details of the underlying advantages and more complete details of the methods used than are presented in this report.

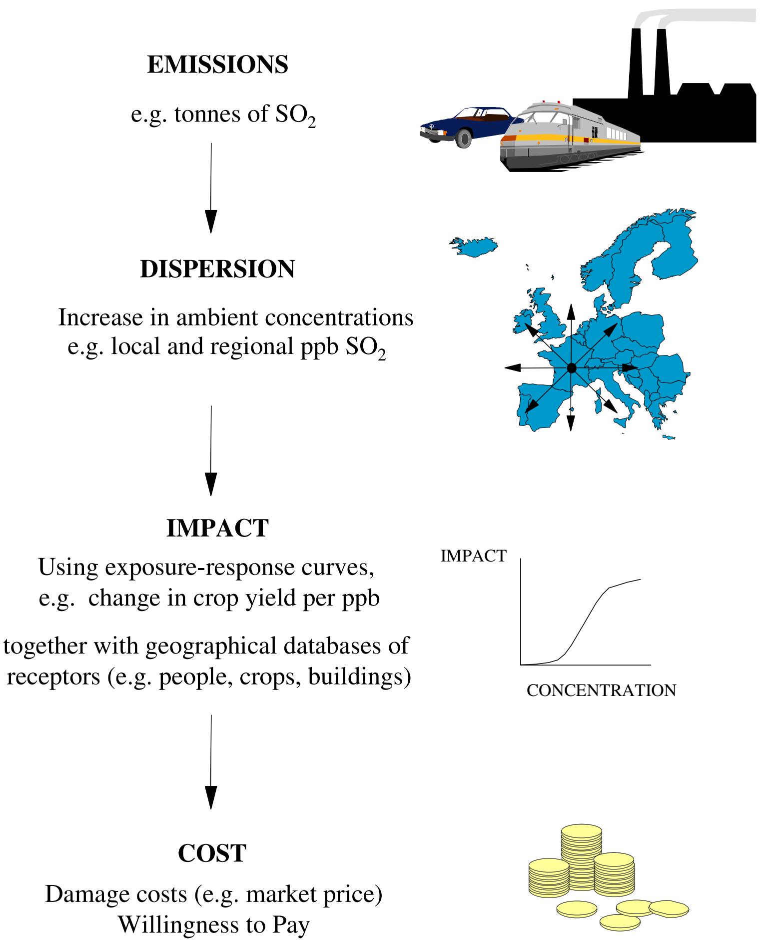


Figure 2 Impact-pathway approach for damage estimation.

This approach forms the basis for the guidance developed in this report. Its main advantages are it allows use of state of the art environmental and health models, can be easily updated, and permits spatial dependence to be taken into account. It can use information relevant to the individual technology and location, which is important in the context of introducing measures to reduce urban energy-use and improve urban air quality. The steps involved in using this approach are described below.

2.7 Valuing the Environmental Effects of Air Pollution

Whilst most project appraisals now consider construction, maintenance and operational costs and compensation payments, to date the costs of environmental effects have rarely been taken into account. For this reason, they are considered ‘external’ to traditional decision making, hence the terms ‘external costs’ or ‘externalities’. The net effect is that these costs are not paid directly by the users of the good or activity causing the pollution. There is therefore a recognition that the monetary evaluation of environmental impacts needs to be incorporated in appraisal and decision support tools.

There have been a number of applications made of the broad methodology used here. These include:

UK policy:

Development of the UK National Air Quality Strategy (DETR 1998:1999)
Investigation of waste strategies for Local Authorities

EU policy:

Economic evaluation of a draft directive to reduce emissions from incinerators (AEA Technology, 1997)
Assessment of the National Emission Ceilings Directive (AEA Technology, 1999a)
Analysis of air quality standards for various pollutants (IVM, 1997, AEA Technology 1998, 1999b)
Priority setting for EU environmental policy (ongoing)

International:

Assessment of the UNECE Protocol to abate acidification, eutrophication and ground level ozone (AEA Technology, 1999c). Some examples of city studies are shown in the box below.

Existing Studies in Developing Countries

The general approach presented has been used for a number of studies, though each use different functions and valuations and are therefore not directly comparable.

Jakarta. World Bank report suggested that PM_{10} emissions in the city alone caused a total of 4,364 excess deaths, 32 million restricted activity days (RAD), 101 million respiratory symptom days (RSD), innumerable emergency room visits, asthma attacks, cases of bronchitis, and hospital admissions at a total cost of about US$300,000 (based on Indonesian data) in 1990.

The World Bank report (World Bank, 1994a) calculated the total economic cost of the health effects of total suspended PM, lead and NOx, using local estimates for health care and lost wages, together with a range of assumptions about mortality costs. For 1990, these range from low of US$97 million (£61 million) to a high of US$425 million (£270 million), with a central value of US$220 million (£140 million). Not surprisingly, suspended PM represent the biggest share of about 70%. Future projections suggest that these values rise to about US$750 million (£470 million) per year (central value) in 1998, US$2.2 billion (£1.38 billion) in 2008 and nearly US$5 billion (£3 billion) in 2018.

The IIEC (1997) report estimates that in terms of total transportation air pollution costs in the city, motor vehicle tailpipe emissions imposed nearly US$165 million (£101 million) in costs in Santiago. Light duty passenger vehicles account for over 40% of the total transport pollution costs, buses for 20%, trucks for 17%, taxis and *colectivos* account for about 14%, and motorcycles for about 7%. Note that these costs only include tailpipe and evaporative pollutant emissions, and exclude lead, SO_x, break and tyre wear. They do not consider fugitive road dust, the impacts of which should also be allocated to transportation, since road dust accounts for nearly 70% of *respirable* particulate matter (PM_{10}) concentrations in the city. When including road dust health impact costs, the share of transportation of total air pollution costs in Santiago would increase by *three* times, to nearly $540 million (£340 million).

The adoption of these tools allows project appraisals to use a Cost-Benefit Analysis (CBA) approach. Such methods compare the discounted user benefits of a scheme, against the total expenditure of the scheme. If the value of the benefits exceeds the discounted capital costs (including land and preparation costs) the scheme has a positive Net Present Value (NPV) and can be justified in economic terms. By including environmental costs, the true costs of options can be assessed, ensuring the optimal allocation of resources and allowing the net positive or negative impacts of environmental policy to be taken into account directly within the decision making process.

Valuing environmental damages in this way is controversial. However, it does provide some important advantages. When the economic costs of a project are compared against qualitative environment impact data, inherent biases exist against the environmental impacts, as priority is given to the economic units of the CBA output.

The most-often voiced objection to valuation is that health, objects of cultural significance and ecology are of such fundamental worth that they are beyond monetisation. However, this ignores the fact that measures for improving the environment cost money[3]. Given that money is in limited supply, it is necessary to make choices to see that it is spent well. Monetisation provides a mechanism for comparing the benefits to be gained from alternative environmental improvement strategies, and hence a framework for deciding how best to spend the money that is available. Given that monetisation is typically based on preferences expressed by members of the public, it would seem to be a very democratic method for deciding how resources should be allocated.

Frameworks, such as provided here, aim to include environmental impacts in monetary terms, so as to provide equal weighting relative to other impacts. Such a framework is particularly important at a strategic level, where planners and decision makers are finding that traditional evaluation schemes are not sophisticated enough to capture the full benefits of their policies, such as urban measures aimed at improving air quality. When evaluated with conventional methods, many such measures tend to show large disbenefits. Therefore, to justify such measures on economic grounds requires appraisal techniques that include the external benefits gained from environmental enhancement. By including environmental costs, the true costs of options can be assessed, ensuring the optimal allocation of resources and allowing the net positive or negative impacts of environmental policy to be taken into account directly within the decision making process.

However, there is a reason why environmental cost-benefit analysis has not been used more widely. To date there has been little consensus over the impact analysis and valuation steps. Indeed, many commentators have concluded that not all environmental effects can be currently (or, perhaps, sensibly) valued. However, the field of environmental economics is progressing rapidly and has led to the development of consistent frameworks for including external cost estimates.

[3] It is acknowledged that some options for environmental improvement do not incur cost, but generate additional profit for operators. An excellent example is the implementation of better energy efficiency, which of course reduces fuel costs.

Given the approach recommended here, once the impacts of air pollution have been quantified in physical terms, the next step in the analysis is to value these damages in economic terms. Some background to monetary valuation is included in the box below.

Valuation

The underlying principle in monetary valuation is to obtain the ***Willingness to Pay*** **(WTP).** In a market, WTP is, to varying degrees, revealed by consumer behaviour. For environmental impacts, the principle is still the same, for example, to obtain the *willingness to pay* (WTP) of an affected individual to avoid a negative impact, or the *willingness to accept* (WTA) payment as compensation if a negative impact takes place. The rationale is that values should be based on individual preferences, which are translated into money terms through individual WTP and WTA (European Commission, 1995). A number of methods have been developed for monetary valuation in such cases.

The first of these, ***Abatement or Avoidance Costs*** takes the cost of a measure as an approximation for the value of the external cost avoided. The rationale is based on the premise that society, by its acceptance of various pollution controls and environmental standards, has demonstrated a willingness to pay for the control of externalities (EPA, 1994). However, it assumes that optimal levels of control are in place. More importantly, the use of avoidance costs also generates the risk of circular reasoning when establishing policy priorities (CEC, 1995). It is therefore not recommended here nor in other recent texts in this field.

An alternative is to establish the ***Damage Costs*** for those goods that are routinely traded. This approach requires the use of direct costs, based on expenditures incurred (or revenues lost) as a consequence of the impact (EPA, 1994). For example, for air pollution this would include: loss in agricultural output in terms of yield loss using crop prices, the additional costs from cleaning buildings and the additional medical expenses from the health effects caused by air pollution. This approach estimates values based on observable market prices. However, for many environmental impacts, such as increased risk of death or loss of recreational amenity, there are no direct or observable market prices. In addition, the approach does not fully capture all WTP effects. For example the cost of illness for health does not reflect the willingness to pay to avoid health damages as it fails to account for the dis-utility of the illness, the defensive expenditures other than for medical care and factors such as the pain and suffering to relatives from mortality. Additional analysis is therefore needed to make the analysis reasonably comprehensive.

In cases where no markets exist, or where the damage cost approach does not fully capture the effect, three techniques are widely used (European Commission, 1995) to estimate WTP. One is to elicit the WTP or WTA by direct questionnaire. This is termed the ***contingent valuation method***. Conceptually this is the closest to what, from the economic point of view, one would ideally like to have - namely an expression of preferences in monetary terms based on a market (CEC, 1996). The approach relies on interviews for quantifying how much individuals would be willing to pay in order to no longer be subjected to a certain level of externality (e.g. traffic noise). Another method is to look at the WTP as expressed in related markets. The approach looks for a complimentary market and observes how environmental attributes affect the market prices of these markets (CEC, 1996). This is termed ***hedonic pricing*** and is widely used for noise and aesthetic effects. Frequently, environmental effects are reflected in property values. Thus an increase in noise or a reduction in visibility will 'show up' in reductions in the value of properties affected by the changes. This provides an implicit valuation of the economic costs of noise. However, such an approach can only reveal the costs of impacts that people are aware of. It also assumes the existence of smooth, continuous trade offs amongst impacts - when in reality the difference will be complicated by other factors. A final method is to assess the expenditure of individuals to benefit from a facility such as a park or a fishing area. This method is known as the ***travel cost method*** and is particularly useful for valuing recreational impacts. It is possible to determine WTP through the expenditures on the recreational activity, including costs of travel to the park, any fees paid, etc.

Contingent valuation or stated preference studies tend to arrive at a higher monetary values than alternative approaches, such as damage costs, hedonic pricing or travel cost methods. This is due to the fact that many more components of the economic value are included than for the case of the other methods, e.g. the others only incorporate 'use' values whereas CVM also includes 'non-use' values (see Pearce *et al*, 1989, p.60 for definition of these terms). The disadvantage of such an approach is these studies are costly to undertake. Attempts are therefore often made to transfer benefit estimates from one location to another, though this raises additional uncertainty with respect to the transferability of any values. There have also been concerns that the method is susceptible to bias, due to the hypothetical nature of CV markets. As a result, guidelines have been drawn up to ensure bias is avoided or reduced to the extent possible in any research studies (Arrow *et al*, 1993).

The valuation methods in the box have been widely used in the US and Europe. There are major issues in transferring the values to the developing world. The transfer and application of existing methods and values from developed to developing countries adds an additional level of uncertainty to external costs estimates. This is because of a number of reasons, including:

- The existence of market subsidies.
- The issue of transferability with respect to economic valuation and the willingness to pay.

As an example, if estimates of damage costs are taken from developing countries, they are likely to be lower than the equivalent damages in Europe/the US. For example, the subsidies of agricultural products will mean lower market prices. For this reason, crop damages are normally valued using international prices.

A greater issue is the transfer of WTP estimates. Some countries are not happy with the use of these estimates anyway (for example, Chinese researchers prefer to use the human capital approach that gives very much lower values). In cases where WTP values are acceptable, and these are the ones that the guidance here recommends, a number of methods can be used for converting values. Further information is provided in Section 2.10, though this area is particularly important for application of this guidance in developing countries .

2.8 Emissions and Air Dispersion Modelling

The methods for calculating emissions from stationary and mobile sources, are well documented. Data on emissions can be found widely in the literature, e.g.:

- for the UK http://www.rsk.co.uk/ukefd/index.htm :
- for the US http://www.epa.gov/airprogm/oar/oaqps/efactors.html :
- for Europe (CORINAIR) http://www.ubavie.gv.at/info/emi/corin94e/Methode.htm .

However, these give factors specific to the technologies and practices in place in developed countries. In some cases, these will also be applicable to developing countries. However, in many cases the technologies in use in developing countries will be older and less efficient and adjustments need to be made to adjust factors to represent local conditions.

The second step of the analysis is to use dispersion models to predict the effects of emissions on air pollution concentrations. There is a huge body of literature air pollution dispersion modelling. The local scale analysis focuses on distances up to (typically) 20 km from the emission source. Gaussian plume models are commonly used for the estimation of local scale atmospheric dispersion of primary pollutants as they combine relatively accurate results and low computing time, though more advanced models have become more widely used over the last couple of years. Models can be downloaded freely from the Internet, for example, US models are available at http://www.epa.gov/epahome/models.htm).

2.9 Assessing the Health Effects of Air Pollution

It is now widely accepted that the air quality levels found in developing country cities are associated with short-term health impacts (WHO, 1999). There is also a broad consensus that the effects of these pollutants on health can be quantified using exposure-response relationships based on epidemiological studies linking general air pollution concentrations to levels of health effects as recorded from statistics and studies.

However, there is not a consensus on which specific health impacts are linked to specific pollutants, and which exposure-response (E-R) relationships should be used to quantify them. Different epidemiological studies have inevitably shown different relationships, and different endpoints, with different pollutants.

Within this study, we have not aimed to review the underlying epidemiological studies concerning pollutants and endpoints. Instead this work concentrates on existing reviews of the literature which have looked at the underlying studies and made judgements on which pollutants and functions should be used. These include:

- The UK Department of Health's COMEAP group (Committee on the Medical Effects of Air Pollutants, 1993:1998);
- WHO Guidelines for Air Quality (1999) (http://www.who.int/peh/air/airindex.htm);
- The ExternE project (EC, 1999, 2000 (http://ExternE.jrc.es/);
- World bank URBAIR guidance (World Bank, 1997).

It should be noted that other review work does exist (e.g. the French Swiss study, US EPA).

In our view, it is helpful to have results from more than one approach, because this reduces the appearance that any one approach is best in all respects, and so leads to some evaluation of the basis for similarities and differences. Although there are differences, there are also overlaps between the various studies in the sets of impact pathways quantified, the associated E-R functions proposed, and the conventions used in health impact estimation. To some extent this reflects independent assessment of the evidence. However, the influence of American epidemiologist Bart Ostro on several of these studies should also be acknowledged. It is likely that steps to increase this consistency between studies will be put in place, under the auspices of WHO, in the coming years.

As a final note, some commentators argue that where specific studies exist, i.e. for the city under analysis, these should be used in preference to International values. We do not believe this is the case. Specific studies do have a clear advantage in terms of relevance, in that these should reflect the local situation more accurately with respect to the specific local pollution mix, the background incidence and health status, etc. However, such functions, being based on an individual city, might be misleading due to random variations and various sources of confounding and bias. Indeed the variation seen between cities bears this out. The use of International values limits the effect of random variations and of any sources of confounding which may have been these effects. Nonetheless, where they exist, we believe that local values should be used for quantification as part of a sensitivity analysis.

The discussion by pollutant is provided below. For more information the reader should refer to the original reports.

2.9.1 Which Pollutants?

Most studies concur that particulate matter (usually expressed as PM_{10}, particulate matter less than 10 microns in diameter) is the main pollutant of concern. Details of the other pollutants relevant to energy are summarised in the WHO guidelines (WHO 1999).

However, it is stressed that there are differences between WHO and other reviews on the causality of other pollutants. Some discussion by pollutant is presented below in the box.

Which pollutants?

Particles. There is substantial epidemiological evidence of adverse acute health effects of particulate air pollution; and strong, but much less widespread, epidemiological evidence of chronic health effects. As particulate air pollution is a complex mixture rather than a single substance, there is a lot of diversity in how particulate air pollution is characterised. This leads to E-R functions for particles in terms of total suspended particles (TSP); PM_{10} (inhalable particles); black smoke (BS); finer fractions such as $PM_{2.5}$ or sulphates; and other indices. It is also possible to `convert' E-R functions from one index of particles to another, using appropriate conversion factors. Such conversion is of course an approximation. E-R functions for ambient particles are generally expressed in terms of PM_{10} as this is the basis of standards (and so of routine monitoring).

Ozone. Both US and European reviews (Touloumi et al, 1997) have confirmed a relationship of ambient ozone with acute mortality and hospital admissions. US functions also include a number of other, less serious, endpoints. The overall evidence strongly supports the view that the acute health effects of ozone can and should be quantified; and that the estimated health impacts from ozone should be added to those of particles. Epidemiological studies represent the effects of daily ozone characterised in various ways; e.g. as 1-hr daily max.; as 5-hr daily average; as 8-hr. daily average; as 24-hr daily average. Conversion factors to functions derived originally using different indices, based on data from some of the studies are available.

Sulphur dioxide. Earlier US studies found the evidence relating to health effects associated with SO_2 as a gas were ambiguous and they were not quantified. This viewpoint is reflected in the WHO guidance. However, the APHEA results in Europe have however established an association of SO_2 with acute mortality, and probably with hospital admissions also, from which E-R functions can be derived. It is however still unclear if these associations with SO_2 are causal. It may be that SO_2 is acting as a surrogate for other pollutants, especially fine particles (e.g. sulphates) not well quantified in the particle measurement. However, in APHEA the size of the apparent SO_2 effect does not depend on the background concentrations of ambient particles, suggesting that it is not a surrogate for PM. European reviews such as COMEAP and ExternE therefore use E-R functions for SO_2 as additive to those for particles and of ozone.

Carbon monoxide. There is relatively little epidemiological evidence concerning CO, so that it is difficult to place in context the results from a few (well-conducted) studies that report positive associations. Specifically, whereas in many studies CO is not examined as a possibly causative pollutant, there are also well-conducted studies which do consider CO and yet do not find a CO-related effect (as the effect of CO is explained by its correlations with other primary emissions). ExternE includes functions for CO and acute hospital admissions for congestive heart failure but discounts other functions for CO and acute hospital admissions for ischaemic heart disease and acute mortality. COMEAP acknowledged that information on CO is accumulating, that assessment may be possible comparatively soon, and that this would be likely to include hospital admissions for cardio-vascular disease and deaths brought forward.

Nitrogen dioxide. Some early US studies reported NO_2 effects. However, subsequent reviews (in Europe especially) suggested that apparent NO_2 effects were best understood not as causal, but as NO_2 being a surrogate for some mixture of (traffic-related) pollution. As a result direct effects of NO_2 were not included in quantification (indirectly, NO_x did contribute, as a precursor to nitrates and to ozone). More recent European studies (APHEA) did find some positive associations between NO_2 and daily mortality or respiratory hospital admissions in several European cities. Consequently, it is possible to propose E-R functions. APHEA however also supports the view that the apparent NO_2 effects may be due to particles; or at least, are highly dependent on background particle levels. Against this background, most reviews do not recommend that the E-R relationships for NO_2 are not used, except for sensitivity analyses.

Lead. The main evidence concerns lead in air and childhood IQ in children. IQ as an endpoint is a very non-specific measure, and there is controversy about what it really represents. However, relationships with blood lead are better established with IQ, and are less variable across studies, than with more specific endpoints. Several studies have considered the possible relationship between blood lead levels and blood pressure. Some suggests a significant weak positive association though there is still insufficient evidence to implicate low level lead exposure as a cause of adult hypertension, as poor exposure data and inadequate consideration of confounding factors limit findings both in occupational and population based studies.

Carcinogens. A number of possible carcinogens are released from combustion. Of these, most concern centres on benzene, 1,3 butadiene and polycyclic aromatic hydrocarbons (PAHs), though other VOCs with potential carcinogenic effects are also released.

Table 1. Pollutants of Concern from Urban Energy Use.

Pollutant	Annual ambient concentration (μg/m^3)	Endpoint	Observed effect level	Uncertainty Factor	Guideline Value (μg/m^3)	averaging time
Carbon monoxide	500 - 7000	Critical level of COHb	n/a	n/a	100 000 10000	15 minutes 8 hours
Lead	0.01 - 2	Critical blood level	n/a	n/a	0.5	1 year
Nitrogen dioxide	10 – 150	Change in lung function in asthmatics	365 –565	0.5	200 40	1 hour 1 year
Ozone	10 –100	Respiratory function responses	n/a	n/a	120	8 hours
Sulphur dioxide	5 - 400	Change in lung function in asthmatics Exacerbation of respiratory symptoms in sensitive individuals	1000 250 100	2 2 2	500 125 50	10 minutes 24 hours 1 year

Source: WHO, 1999.

Effects can be categorised into mortality (death) and morbidity, and also into acute (short-term effects associated with levels of pollution on the same day or on subsequent days) and chronic effects (long-term effects from exposure over months or years).

The recommendations for health assessment for this study are summarised below.

2.9.2 Acute Effects

Acute mortality

All the studies provide functions for PM_{10} and "acute mortality" (the conventional shorthand way of referring to deaths brought forward as a consequence of acute, or short term, exposure to air pollutants). For this guidance, we have proposed the use of the WHO recommendations, which also form the basis of those given by COMEAP (the Department of Health's Committee on Medical Effects of Air Pollutants) in the UK. This considered 17 studies including 12 in the US, three in Europe and 2 in Latin America.

The European studies also include functions for SO_2 and acute mortality and the functions recommended in COMEAP have also been included in the guidance here. This is based on a meta-analysis from the results of the APHEA study (Katsouyanni et al, 1997). Both US and European studies have functions for ozone, though consistent with COMEAP, the guidance here recommends the use of the results of APHEA (Touloumi et al, 1997).

Note all studies (e.g. COMEAP, ExternE) highlight that although quantification of deaths brought forward is possible, they do not allow us to estimate by how long. Moreover, in the developed world, many of the deaths associated with pollution are probably in the elderly and the sick, hastening death, and so the period of life lost may be small. There is strong evidence that a younger age group is affected by acute mortality in developing countries and for these people, the period of life lost may be much greater (see section below on using functions from developed countries).

Respiratory hospital admissions

After acute mortality, the greatest consensus regarding health endpoints is for respiratory hospital admissions. Following the approach above, the guidance here uses the recommendations of COMEAP for quantifying PM_{10} related effects, which is taken from WHO recommendations based on six cities, four in the US, one in Canada and Paris. COMEAP recommendations are also used for SO_2 and ozone, based on meta-analysis from the results of the APHEA study (Katsouyanni et al, 1997: Touloumi et al, 1997). As with acute mortality, US literature (and WHO guidance) do not include the relationships with SO_2.

Other hospital admissions

Direct evidence for PM_{10} and a number of other hospital admissions are found in most reviews. For the guidance here, we have taken the recommendations from ExternE, which has sought to balance US and European data and studies. Effects relating to cardiovascular hospital admissions and cerebrovascular hospital admissions are recommended, as well a relationship between and CO and admissions for congestive heart failure.

Acute effects in asthmatics

The health impacts on asthmatics of increased use of medication (bronchodilator usage), increase in respiratory symptoms, and cough were considered in two European studies (Dusseldorp et al 1995, Roemer et al 1993) and one US study, Pope and Dockery (1992). These relationships have been included, as recommended by ExternE, which includes a downward adjustment for the US function. An additional function from ExternE for O_3 and asthma attacks from Whittemore and Korn (1980) is also included.

Restricted Activity Days (RADs) and Respiratory Symptoms

The evidence linking RADs quantitatively with air pollution is among the weakest of all endpoints, because the underlying studies are cross-sectional rather than longitudinal in nature (see IOM, 2000). Available studies are all from the US and have been included in this guidance on the basis of recommendations from ExternE. In ExternE a function for PM_{10} and RADs was based on Ostro (1987), one for minor restricted activity days from ozone exposure was taken from Ostro and Rothschild (1989) and one for respiratory symptoms in the general population was based on a large-scale study in California (Krupnick et al., 1990).

Emergency room visits (ERVs)

Many reviews include emergency room visits, based on North American studies. However, this is one endpoint where we believe that differences in health care systems mean that application in other countries, especially developing countries, may be misleading. We therefore do not recommend any functions for ERVs in this guidance.

2.9.3 Chronic Effects

Chronic mortality (PM)

There is controversy about whether longer-term (chronic) exposure to ambient particles causes premature mortality in ways that are not captured by the time series studies of acute mortality. There is evidence from a number of US studies including Pope et al (1995) involving about 500,000 individuals in 151 US cities, as well as earlier studies Dockery et al

(1993) with approximately 8,000 people in six cities. In effect, these studies show that the mortality rate was higher in more polluted areas.

However, translating these studies into functions that can used for assessing chronic mortality (change in life expectancy) from pollution is difficult. There is some debate whether and how the impacts can be estimated using results from a small number of cohort studies carried out in the USA. It requires judgements about the degree of latency, the importance of historical exposure as well as details of the life expectancy of the population under analysis. The ExternE project has made progress in deriving such functions and has implemented them for Europe, using age-specific death rates and assumed latency periods. A more detailed study (IOM, 2000) has recently been completed for the UK Department of Health, and is currently under peer review. It is, however, questionable whether the functions identified could be applied to developing countries (see section 2.9.4). This causes a dilemma. Chronic mortality effects, if real, are likely to be among the most important of all health endpoints considered.

Chronic morbidity from particles

A number of the US studies provide evidence for chronic (long-term) effects from PM on adults and children. These include chronic bronchitis and chronic cough. As with chronic mortality, the uncertainty in using these functions for application in developing countries raises additional issues of transferability. Again we do not recommend their use in the guidance, though stress that they should be considered as part of sensitivity analysis.

Carcinogensis

The potential carcinogenic effects of benzene, butadiene and PAHs are also chronic effects. Unit risk factor (URF) from the US can be used to estimate the potential carcinogenic risk from exposure. These are based on the estimated probability that a person of 'standard' weight will develop cancer due to exposure (by inhalation) to a concentration of $1 \mu g/m^3$ of a pollutant over a 70-year lifetime. As with other studies, an annual risk can be obtained from assuming a 1-year increment increases the lifetime risk of cancer by 1/70 of the URF.

It should be noted that the basis of epidemiological evidence for these effects is generally much weaker and usually involves extrapolation (from animal studies or epidemiological studies of workers exposed to high concentrations). There are major methodological issues when using either occupational and/or animal studies for quantitative human risk assessment. Because of this extra uncertainty and because these are chronic effects which are dependent upon assumptions which are likely to be very different in developed and developing countries, we only recommend use of these estimates for sensitivity analysis.

Lead and IQ

The final category of chronic effect is from lead and IQ in children. The analysis of lead is more complicated as it involves two components: the relationship between lead in blood and childhood IQ; and the relationship between lead in air and lead in blood.

IQ as an endpoint is a very non-specific measure, and there is controversy about what it really represents. However, relationships with blood lead are better established with IQ, and are less variable across studies, than with more specific endpoints. Functions are included based on

Schwartz (1994) assuming conversion factors relating lead in air to lead in blood, based on the assumptions used in ExternE. As the adverse effects of exposure to lead will be greatest when the child's nervous system is developing most rapidly, the biologically relevant exposure is assumed to occur over three years, aged 0-2 inclusive. It also assumes the relationship refers to children at age 10. This implies a time-lag of about nine years, between exposure (at 18 months) and effect (at 10.5 years), which is relevant for discounting. The conversion factor for lead in air to lead in blood of: 1 $\mu g/m^3$ in air ~ 5 μg/dl in blood and so ~ 1.25 IQ points is used. Again it is stressed that as this is a chronic effect, uncertainty is higher.

2.9.4 Using Functions from Developed Countries in Developing Countries

The bulk of studies linking air pollution to health impacts have been undertaken in the US and Western Europe. A crucial question, in the absence of large numbers of developing country studies on the health effects of air pollution, is whether the dose-response functions from the developed world can or should be used to assess health effects in developing countries.

The background factors and levels of morbidity and mortality in a developing country are likely to be very different to developed countries in many respects. There is likely to be a different age structure (more young individuals). There is also likely to be very different health service provision and health care system. It should also be noted that although many of the underlying conditions are very different in developing countries, the pre-disposing factors such as general health conditions, access to medical care, behavioural patterns (smoking) are likely to be less favourable. There are also likely to be big differences in exposure profiles as exposure may differ between the epidemiological study population (e.g. the US) and the target population at risk. This will arise because of the ratio of time spent indoors and outdoors, ventilation rates in houses (which are likely to be higher in hotter countries and those that are less well insulated generally) and due to general human activity patterns.

Some studies have applied US dose-response functions directly to the developing world (e.g. World Bank Jakarta studies - Ostro, 1994: 1996). However, there have been a number of well established attempts to consider the health impacts of air pollution in developing countries. These include Santiago, Chile - Salinas & Vega, 1995; Santiago, Chile - Ostro *et al* (1996) Beijing, China - Xu *et al*, (1994); Mexico City, Mexico - Borja-Aburto *et al* (1997); Sao Paulo, Brazil - Saldiva *et al*., 1995.

Interestingly, the general evidence from these studies is that the exposure-response relationships in terms of percentage change do not differ from those found in more developed countries, and suggests that they are transferable.

There is one factor that is particularly important here. Some studies (e.g. Cropper et al, 1996, Delhi, India) indicate that impacts of air pollution on deaths by age group may be very different in developing countries than in the US or Europe. In Europe and the US, many of the deaths associated with pollution are probably in the elderly and the sick, hastening death, and so the period of life lost from air pollution related mortality may be small. In Dehli, peak effects occur in the 15 – 44 age group. Childhood mortality is also higher in developing countries, for example acute respiratory infections account for nearly 15% of all mortality among children under the age of five in Jarkarta.

Given that younger people are dying from air pollution in developing countries, there are two possible interpretations that can be taken. Firstly, the people who die would have otherwise recovered and therefore are losing a large number of years of life. This has very important implications as to the importance of these deaths when compared to the situation in Europe and the US. Secondly, that although the people who die in developing countries are younger, they are also people who are sick or have existing illness and would have died in the near future anyway, i.e. they lose a similar life expectancy to that seen in an older population in developed countries. At present there is no information to judge which of these is the case, though as we shall see in the valuation section, it has major impacts on the importance attached to these impacts.

Finally, there is the question of whether chronic effects can be equally applied in developed and developing countries. Given the uncertainty related to these effects in developed countries, their application to areas where many of the key factors (life expectancy, historical exposure to pollution, etc) are very different indeed, means that transferability is questionable. We do not, therefore, include them in the main recommendations here. However, as these may be amongst the most important impacts, we recommend they are included in the sensitivity analysis. This, essentially, builds the analysis in a robust way, distinguishing those effects that we believe can be quantified with confidence, from those that are more uncertain.

2.9.5 Implementing the functions

There are additional issues concerned with the implementation of the functions. These are beyond the scope of this report, though a full discussion can be found in other reports (e.g. European Commission, 1995). For ease of implementation, the functions are generally implemented linearly, independent of background and in particular, without threshold. These two assumptions are very important (and to some extent controversial), though there is some evidence to support both assumptions (see European Commission, 1995).

Exposure response functions are usually presented in one of two ways:

1) % change in the number of events (relative risk) of any given type, normalised by unit pollution. This is applied to a baseline rate.
2) Absolute change in the number of events of any given type, normalised by unit pollution and size of population.

Both involve important issues with respect to transferability.

The second is easier to implement and must be used where data on the number of events are unavailable, or where concern exists as to whether the endpoint definition used is identical to that adopted in the original epidemiological work. The first is perhaps more accurate (as potentially it does not assume transferability of background rates, though as the uncertainty section states, this is not necessarily the case).

The extent to which the available data correctly quantify the impact referred to by the exposure-response functions identified is an important issue. At this point it should be noted that some inconsistencies are present, making estimates of some impacts from functions expressed as % change in number of events per unit pollution unreliable. Further discussion on the uncertainty this introduces is presented in the next section.

The actual implementation of this approach relies on linking the pollution concentrations and dose-response functions to population data - to provide the likely increments in health events. Thus, for implementation, the geographical area to be considered is sub-divided into smaller regions using a regular grid system (for example a 1 km^2 grid across London with the option of higher resolution close to the source itself).

Each grid-cell is considered as a micro-environment with a homogeneous pollutant concentration. For ease of implementation, the associated population at risk is the population resident in that grid-cell. As in the epidemiological studies, daily movements of people between grid-cells are not addressed explicitly, though they may well be accounted for (implicitly) in the functions. Thus, the approach requires data on the population distribution. The level of resolution of the population data can range from generic population density types (e.g. city centre, town, rural, etc.) to detailed census data.

The use of GIS allows the simple combination of population data and pollution data, and can quickly and accurate calculate health effects from pollution by simply multiplying population weighted exposure by the functions. Of course, using above approach takes time and effort. At the wider policy level, a simplified approach can be used, taking values (e.g. impacts per tonne of pollutants) derived from bottom-up studies. This, however, does not take specific account of the location specificity of damages – an extremely important factor.

2.9.6 Implementing the functions – indoor air pollution

There is one aspect of implementation that is not well characterised in the literature: that of indoor air pollution. In developed countries, any health effects that occur from indoor air pollution are included in the reported health statistics and therefore in the exposure-response functions. To account for indoor air pollution separately will therefore lead to double counting (this assumption is valid as the use of solid fuels for indoor space heating and cooking is limited).

However, the same assumptions cannot be used for developing countries. The scale of solid fuel use in the home is very large indeed - half the households in the world use solid fuels on a daily basis (WHO, 1999). In the urban areas of developing countries, it is therefore likely that indoor air pollution leads to health effects that are additional to the health effects that arise from ambient air quality concentrations. This is because of the much higher concentrations that arise in homes when solid fuels are used. Indoor air particulate concentrations can be extremely high – levels of several thousand $\mu g/m^3$ are common – compared to levels of tens – hundreds of $\mu g/m^3$ for ambient air pollution.

It would therefore be expected that in cases where there is a large use of coal for domestic fuel supply, epidemiological studies (linking ambient levels with reported health effects) should show greater numbers of cases per unit of pollution because of these additional impacts. However, it is not clear that the evidence reflects this – as described above, functions in developed and developing countries are very similar in terms of the impacts per unit of pollution. It may be that the very high levels of ambient air pollution in developing countries may mask health effects from indoor air pollution, or it may be due to other reasons (e.g. the shape of the functions).

Unfortunately the epidemiological evidence relating to indoor air pollution is less well reported. The studies that do exist, e.g. see Appendix on the use of domestic coal in the

RSA, indicate that health effects from these sources could be very important. However, the information to deal with the differences in the balance of pollutants and levels of exposure, and indeed as to whether these might lead to different health end-points, are not know. What evidence exists, (e.g. WHO, 1999) seems to report three main effects from indoor air pollution (especially coal): acute respiratory infections in children, chronic obstructive pulmonary disease, and lung cancer.

Previous applications of dose-response functions to predict health impacts from indoor pollution in developing counties (e.g. World Bank, 1997) have used the sort of functions listed above for ambient air pollution (section 2.9.2) and applied them to the estimated indoor concentrations. The impacts that arise are then treated as additive to other health effects quantified from ambient air pollution concentrations. This approach may provide an initial indication to the possible levels of health effects (provided the International functions are used rather than local functions, as the latter would be expected to already include these health cases in the reported statistics). However, a much higher uncertainty must be attached to such estimates, because of the uncertainty in applying these functions to indoor air pollution at the very high concentrations found indoors in these cases (e.g. as it maybe that the slope of the functions above flattens at very high concentration levels). This area is highlighted as one that warrants further research.

2.9.7 Uncertainty

The above discussion shows that there are alternative approaches with respect which pollutants, which endpoints and which functions can or should be used in quantification. This is related to the wider category of the uncertainty with such quantification methodologies.

Quantifying the sources of uncertainty is problematic because of a general lack of information. Uncertainties can be grouped into different categories, even though there may be some overlap:

- Data uncertainty (e.g. slope of a exposure-response function, deposition velocity of a pollutant);
- Model uncertainty (e.g. assumptions about causal links between a pollutant and a health impact, assumptions about form of a exposure-response function (e.g. with or without threshold), and choice of models for atmospheric dispersion and chemistry);
- Idiosyncrasies of the analyst (e.g. interpretation of ambiguous or incomplete information).

The first category (data uncertainties) is of a scientific nature. It is amenable to analysis by statistical methods, combining the component uncertainties over the steps of the pathway, to obtain formal confidence intervals around a mid estimate. The other areas are different and invariably bring the greatest source of uncertainty, as they centre on the choice of pollutants, endpoints and functions themselves. The functions or endpoints included invariably fall back on subjective judgement by experts.

There are a number of issues that are commonly cited as of concern. Given that particles dominate the health effects, the fact that the mechanism of effect for most endpoints is not well understood is a problem. There are also other issues involved. PM_{10} is a complex mixture (with respect to size and composition) and it is not known which (all or part) of the mixture is causal. There is evidence that particles (primary and secondary) from combustion are more strongly associated with effects, as are the smaller size fractions ($PM_{2.5}$, and possibly even PM_1). Note however, that any changes in the causality of different fractions has implications in wider implementation – if some fractions of the mixture are not causal, it means the levels of impacts from the remaining fraction is higher per unit value than currently estimated.

There are also issues with implementation regarding a number of areas, especially

- Can the functions be implemented linearly without threshold.
- Are the functions (and background data) transferable.

For many of these pollutants, there clearly is a threshold at the individual level; e.g. daily pollution will not lead to sudden death in healthy individuals. There is not however good evidence of a threshold at the population level; i.e. it appears that, for a large population even at low background concentrations, some vulnerable people are exposed some of the time to concentrations which do have an adverse effect. This understanding first grew in the context of ambient particles, where the 'no threshold' concept is now well established (though it is however difficult to demonstrate no threshold by epidemiological methods because of the small signal and sparse data points).

The issue of transferability is a more serious one. Results in Europe from APHEA show important differences between estimated effects of particles in ‘Western’ and ‘Eastern’ Europe. Some differences also exist between epidemiological studies in North America and Europe. These may be due to of differences in the nature of the pollution mix, or the concentration levels. They may also vary for other reasons.

Consideration of the transferability of exposure-response data from specific locations in the UK, the rest of Europe, or the USA to the UK is complex. The issues here of most importance to the implementation of the functions divide into three categories. The first concerns the scheme adopted for collection of air quality data;

- Type of monitoring equipment used
- Number of monitors/spatial resolution of system

The next category concerns the link between air quality and the dose of pollutant inhaled;

- Behaviour of population (modes of transport used, time spent outdoors in heavy traffic areas, or in buildings with windows open overlooking busy streets)

It is necessarily assumed that there is no variation in behaviour, though this is clearly a significant simplification when comparing personal exposure regimes between countries with very different climates, or different standards for vehicle emissions. Ideally therefore, some account needs to be taken of these issues when selecting functions.

Finally, a category that reflects the responsiveness of the population;

- Health state of population;
- Age structures of population;
- Access to medical services.

These issues are accounted for by the use of the set of functions given below based on % change in the number of events of morbidity and mortality. There remains a problem, however, with the consistency of disease reporting between countries. This is most problematic for minor effects, such as ‘restricted activity days’.

Functions are described as 'acute' (short term) or 'chronic' (long term) relating to the period of exposure to air pollution required for the effects identified to arise in association with air pollution.

Finally, the functions in the report are generally intended for use with pollution increments, as would be the case for looking at incremental pollution changes from transport schemes, policies or options. There are some concerns about applying them to look at total air pollution, or as in the example below with all transport-related pollution, as these are non-marginal changes.

In conclusion, there are significant uncertainties for the types of health frameworks presented here. It is frequently argued that in cases where uncertainties are potentially large, as here, it is not appropriate to conduct quantification. We believe that this is wrong. By reviewing uncertainties it is possible to develop an understanding of the potential risks of different policies to society in terms of, on the one hand, potentially unnecessary expenditure on pollution prevention schemes, and on the other, potentially excessive health damages. Finally, we stress that methods for dealing with uncertainty are being successfully developed, greatly assisting the understanding of benefits assessment (see AEA Technology, 1999a).

2.9.8 Summary of Recommendations

The recommended functions are presented below, broken down into the uncertainty classes.

Within endpoint, effects are considered as being additive across pollutants (particles, ozone, SO_2) unless otherwise stated. Note however, that different endpoints have different levels of uncertainty.

The functions for acute mortality and respiratory hospital admissions are summarised below. We attach the highest level of confidence to these estimates.

Table 2. Exposure-Response Functions, band I (highest certainty).

Impact Category	Pollutant	E-R function
Deaths brought forward (all cause)	PM_{10}	0.75 % per 10 μg/m^3 (24 hr mean)
	SO_2	0.60 % per 10 μg/m^3 (24 hr mean)
	Ozone	3.0 % per 50 μg/m^3 (8 hr mean)
Respiratory Hospital Admissions (RHA)	PM_{10}	0.80 % per 10 μg/m^3 (24 hr mean)
	SO_2	0.50 % per 10 μg/m^3 (24 hr mean)
	Ozone	3.5 % per 50 μg/m^3 (8 hr mean)

Note, these are expressed in terms of a % change in background rates per μg/m^3 increase in pollution as data on death rates exist for most countries and respiratory hospital admissions for many countries

Note, these are expressed in terms of the absolute change in the number of events of any given type, normalised by unit pollution and size of population, as data on the background events of these functions is unlikely to be available. This does mean there are additional assumptions about background levels and their transferability.

Data are needed on the % of the population by age (adults, i.e. those over 15 years of age: elderly, i.e. those aged more than 65 years) though this data are usually available. Information on asthmatics is more difficult, though in the absence of data, regional statistics can be used.

Table 3. Exposure-Response Functions, band II (medium certainty).

The exposure response slope, f_{er}, has units of case events per year per person per μg/m^3.

Receptor	**Impact**	**Reference**	**Pollutant**[1]	f_{er} [1]
ASTHMATICS				
Adults	Bronchodilator Usage	Dusseldorp et al, 1995	PM_{10}	0.163
	Cough	Dusseldorp et al, 1995	PM_{10}	0.168
	Lower respiratory symptoms	Dusseldorp et al, 1995	PM_{10}	0.061
Children	Bronchodilator usage	Roemer et al, 1993	PM_{10}	0.078
	Cough	Pope and Dockery, 1992	PM_{10}	0.133
	Lower respiratory symptoms	Roemer et al, 1993	PM_{10}	0.103
ELDERLY 65+				
	Congestive heart failure	Schwartz and Morris, 1995	PM_{10}	1.85 E-05
			CO	5.55 E-07
ADULTS				
	Cerebrovascular hospital admissions	Wordley et al, 1997	PM_{10}	5.04 E-06

Sources: (EC, 1995) and (Hurley et al., 1997).

Table 4. Exposure-Response Functions, band III (highest uncertainty). The exposure response slope, f_{er}, has units of case events per year per person per μg/m^3.

Receptor	**Impact**	**Reference**	**Pollutant**[1]	f_{er} [1]
ASTHMATICS				
All	Asthma attacks (AA)	Whittemore & Korn, 1980	O_3	4.29 E-03
ADULTS				
	Restricted activity days (RAD)	Ostro, 1987	PM_{10}	0.025
	Minor RAD	Ostro and Rothschild, 1989	O_3	9.76 E-03
	Symptom days	Krupnick et al,	O_3	0.033

Sources: (EC, 1995) and (Hurley et al., 1997).

Table 5. Exposure-Response Functions Chronic Effects, band IV (sensitivity only). The exposure response slope, f_{er}, has units of case events per year per person per μg/m^3.

Receptor	**Impact**	**Reference**	**Pollutant**[1]	f_{er} [1]
CHILDREN				
	Chronic cough	Dockery et al, 1989	PM_{10}	2.07 E-03
	IQ	Schwartz (1994)	Lead	
		2.57 IQ points per 10 μg/dl blood lead; in school-age children.		
ADULTS				
	Chronic bronchitis	Abbey et al, 1995(after scaling)	PM_{10}	2.45 E-05
ENTIRE POPULATION				

Chronic Mortality(CM)	Pope et al, 1995 (after scaling)	PM_{10}	
470 YOLLs per 100,000 current population (all ages) per 1-yr. increase of 10 μg/m^3 PM_{10}.			
Cancer risk estimates	Pilkington et al, 1997; based on US EPA	Benzene 1,3-butadiene	1.14 E-07 4.29 E-06

Sources: (EC, 1995) and (Hurley et al., 1997).

Examples of how the functions are used are presented in the Appendix in country case studies.

Geographical range of effects

The assessment of air pollution impacts in this work concentrates on local air quality. However, the pollutants of interest also impact at a regional level over distances of perhaps a thousand kilometres or more, through pollutants in both their primary form (i.e., the chemical state in which they were emitted) and as secondary pollutants (i.e., following chemical reaction in the atmosphere).

These regional effects are more difficult to assess without detailed information on background emissions, meteorological data and the regional receptor data. Such an analysis is too detailed for the scope of this initial project. However, it is important that these regional effects should be highlighted as warranting attention in future work. They are accounted for already in the European studies (e.g. AEA Technology 1999a, c).

2.10 Valuation of the Health Effects of Air Pollution

In recent years, there has been more of a consensus on the approaches used to value health effects from air pollution in Europe and the US, though there remains debate on the exact values to use. Valuation is usually based on WTP, which encompasses the costs of illness borne by the individual, plus any foregone earnings. In addition any social costs of illness should be added. The WTP for an illness is thus composed of the following parts:

- The value of the time lost because of the illness;
- The value of the lost utility because of the pain and suffering;
- The costs of any expenditures on averting and/or mitigating the effects of the illness.

Contingent valuation is used to estimate the value of pain and suffering. The costs of illness (COI) are based either on the actual expenditures associated with different illnesses, or on the expected frequency of the use of different services for different illnesses. To date, most estimates have generally estimated the costs of air pollution induced hospital cases by using unit cost values based on costs of illness. These costs include production loss costs of employees.

The WTP studies for a range of ***morbidity*** endpoints associated with air pollution have been undertaken in the US and EU values, based on CVM surveys. More details of such endpoints and their values derived are presented elsewhere (European Commission, 1995). Morbidity endpoints (from ExternE, 2000) are shown below.

Table 6. Values for Health Endpoints.

Endpoint	Euro
Bronchodilator use	40

Cough	45
Lower Respiratory Symptom (wheeze)	8
Asthma attacks (AA)	75
Congestive heart failure	3260
Chronic cough	240
Restricted Activity Day (RAD)	110
Minor RAD	45
Chronic bronchitis *	169330
Respiratory Hospital Admission	4320
Cerebro-vascular Hospital Admission	16730
Symptom days	45

The valuation of ***mortality*** is based on the estimation of the willingness to pay for a change in the risk of death, converted into the 'Value of a Statistical Life' (VSL) by dividing the WTP by the change in risk. The mean value from European studies give values of £2-3 million). On average, the highest values come from the CVM studies and the lowest from the consumer market studies where actual expenditures are involved. Because of uncertainties in some of the higher values, a best estimate of £2 million (1990) is used.

As mentioned earlier, the valuation of mortality from air pollution does raise a number of additional complications. From the epidemiological studies, it appears that the excess deaths from (particulate) air pollution in Europe and the US are principally from cardio-respiratory causes in older, already ill people and that the associated loss of life may, on average, be small. The Ad-Hoc group on the Economic Appraisal of the Health Effects of Air Pollution (EAHEAP, 1999) was set up by the Department of Health arrived at alternative WTP values for reductions in air pollution mortality risks (£2,600, £110,000, or £1.4million). However, most practitioners in this are use the central value for implementation, using a relative years of life lost approach. This is similar to the value used in other studies such as ExternE. However, it is not clear that such an effect is warranted in application to developing countries – it seems the age group affected by respiratory related mortality is different to developed countries, and it may be that the full VSL is warranted. A full account of these issues can be found in the ExternE methodology report (European Commission, 1995a).

Air pollution is also thought to have chronic fatality effects, i.e. air pollution concentrations in areas of high pollution are thought to result in a shortening of life expectancy. These impacts are difficult to value, not least because of uncertainties in the quantification. Nonetheless, they are important, particularly for urban areas. Approaches and valuation estimates are emerging which can be used for such assessments and they should be considered in frameworks.

For both mortality and morbidity, adjustments in values need to be made for application in developing countries. In some cases local data will exist, e.g. local COI figures. However, in most cases values are transferred from the US/EC values. Values are normally adjusted down either on the basis of the ratio of wage rates, or on the ratio of real GNP in the country to the real GNP of the EU or US (also referred to as Purchasing Power Parity (PPP) Adjusted GNP).

2.11 Assessing the Non-Health Impacts of Air Pollution

There are a number of other environmental effects from air pollution. In the urban context, the most important of these are the impacts on buildings and materials. In the context of developing countries, impacts on buildings are very much less important than issues associated with health effects. However, failure to implement basic cleaning and repair (e.g. arising from air pollution) actually leads to much greater effects and higher costs of repair in the long term – damaging the underlying building fabric and actually putting a greater burden on areas with limited resources. There is one final issue to raise: air pollution also damages cultural and historic buildings. The potential damage to monuments, as is happening with the Taj Mahal in India, are important (especially if irreversible), partly because tourist revenues may be reduced, but also because of the damage to cultural heritage.

2.11.1 Building Soiling

Soiling of buildings by combustion particulates is one of the most obvious signs of pollution in urban areas. The soiling of buildings includes both residential dwellings and historic buildings and causes economic damages through cleaning costs and amenity costs. Particles may also be involved in damage to the building fabric.

Soiling is an optical effect (a darkening of reflectance) and results primarily from the deposition of airborne particulate matter to external building surfaces. The degree of soiling depends on a number of factors which include (QUARG, 1996): the blackness per unit mass of smoke; the particle size distribution; the chemical nature of the particles; substrate-particle interfacial binding; surface orientation; and micrometerological conditions. Similarly, different types of particulate emission have different soiling characteristics. They can be differentiated by fuel type with the use of dark smoke emission factors (Newby *et al*, 1991; Mansfield *et al*, 1991). For example, diesel emissions have a much higher soiling factor relative to petrol or domestic coal emissions, due to their particulate elemental carbon (PEC) content (QUARG, 1993). PECs have a high optical absorption coefficient and their hydrocarbon content means they are very sticky and much less water soluble than suspended soil particles (which are readily removed by rain washing (Mansfield, 1992)). Therefore, a PEC particle landing on a surface is more likely to strongly adhere than other particulate matter.

Although soiling damage has an obvious cause and effect, the quantification of soiling damage is not straightforward. Soiling can impact on a number of different materials, including natural stone, paint, concrete, rendering and also glass (windows). Measurement data of reflectance and industry experience show that soiling appears to be very rapid on clean surfaces, following initial exposure, i.e. it is non-linear. Moreover, evidence shows that reflectance measurements oscillate, indicating a cleansing and re-soiling process. This may occur as soil derived particles may be deposited on materials but are more likely to be removed by rainfall than a deposited diesel particle.

Some exposure response functions do exist. These link particle concentrations to loss of reflectance for a surface. Once a certain critical loss of reflectance is reached (usually a 70% reduction), then it is assumed that cleaning would occur (in order to value the potential impact). The data of Pio et al., (1998), gives criterion for the critical soiling doses for sheltered painted wood and limestone due to soiling of 533 and 352 year·µgTSP/m^3, respectively. Given the concentrations of particles in urban areas of developing countries this would mean that soiling should be a major factor (for example, at the levels of pollution seen in Chinese cities, the critical level would be reached every 2 years after cleaning. However, there is another important point. Building soiling is usually more strongly associated with transport emissions as these are emitted at ground level immediately next to buildings. Emissions from high stacks do not result in building soiling – this can be seen in the lower levels of building soiling in Chinese cities, where coal is a dominant source of particles, as compared to South-American and South-east Asian cities where transport is a greater issue.

There are also some additional questions of transferability. Of course, cleaning does involve a behavioural element. Work on the UK cleaning industry indicates appearance is the most important criteria, rather than behaviour. However, given the economic status of developing countries, building cleaning will be a lower priority. Note that this does not mean damage is lower as failure to clean buildings regularly can lead to greater damages later on. For example, as with stone when acidic deposition and particle deposition combine to form a crust which can fall-off (exfoliate) due to alternate wet/dry and freeze/thaw cycles with the loss of underlying material. Therefore, failure to clean may lead to greater economic damage in the longer term. There is also an amenity issue, in terms of the visual appearance of dirty buildings.

The other problem common to all building analysis is the lack of building inventory data. Such data exists for Europe and the US, where the types and quantities of materials used in different buildings are known.

As a result, a detailed approach using exposure-response functions and a stock at risk is not currently possible for building soiling. An alternative method must be used, and the easiest approach is to take estimates of cleaning costs in cities and link these to emissions and air pollution data. Data is collated on the building cleaning market in a city and linked to annual ambient air pollution levels to provide a cost per $\mu g/m^3$. This includes cleaning of historic buildings and monument. Previous estimates using this approach in Europe give value of between £200 and £500 per tonne of particles emitted (EC, 1999). It is possible that soiling also has a role in determining window cleaning, though other factors (natural dust, rainwater) also are important factors.

2.11.2 Erosion and Corrosion of Building Materials

The effects of atmospheric pollutants on buildings has been well documented over many years and clear mechanisms linking pollution to material damage have been identified. Sulphur dioxide has emerged as the key pollutant associated with material erosion, both directly (through dry deposition) and indirectly through the formation of secondary pollutants (acidic deposition). These damages have been recorded on modern buildings and other modern infrastructure as well as historic buildings.

Urban energy-related emissions therefore have a large potential effect on buildings, with high SO_2 levels of particular concern. The materials for which damage occurs calcareous stone, mortar, paint, concrete, aluminium and galvanised steel. Although not exhaustive, this list includes the most sensitive of the materials commonly used in the construction industry.

The ability of air pollution to damage **natural stone** is well known. Reviews have concluded that damage from acidic deposition is important for calcareous stones, i.e. limestone and calcareous sandstones. Stone, both in historic and modern buildings therefore has a high sensitivity to energy related pollution.

In contrast, **brick** is unaffected by sulphur dioxide attack, though air pollution does damage mortar through acid attack on the calcareous cement binder, which in turn leads to loss of the inert silica aggregate.

Concrete is potentially susceptible to acid attack (via the alkaline cement commonly used as a binding agent) however damages are more likely to occur as a result of natural carbonation and ingress of chloride ions, rather than interaction with SO_2 and so the sensitivity to energy related pollution is low. There is a view that damage from acidity to the steel elements in re-informed concrete could be particularly significant.

SO_2 is also the principle cause of the atmospheric corrosion of **metals**. Steel is corroded quickly by air pollution, and as a result is usually painted or galvanised (with zinc, which has a lower corrosion rate than steel, but is corroded in preference to it and thereby acts as a protective coating).

Damage to **paint** can also occur from acidic attack, with erosion of surfaces, loss of paint adhesion from substrates and interaction with sensitive pigments and fillers such as calcium carbonate. However, the assessment of paint is complicated by natural weathering and from behaviour aspects.

Ozone is also known to damage some polymeric materials such as **plastics and rubbers** (Lee *et al*, 1996). A recent research programme has found that there is no evidence in support of a significant effect of O_3 on paints (Holland *et al*, 1998b) in contrast with previous evidence. However, effects were found on rubber products. For predictive purposes, a simplified exposure-response function developed by Holland *et al* (1998b) though these are not easily transferable because of the need for ozone data, and the specificity of the results to the stock at risk in the UK.

In developing countries other materials are also likely to be important, especially the use of wood.

As with health, exposure-response relationships can be used to estimate impacts. For several materials that are frequently used in buildings *exposure-response functions* have been obtained. A physical damage function links the rate of material corrosion (due to the pollution exposure given by the dose-response function) to the time of replacement of maintenance of the material.

Performance requirements determine the point at which replacement or maintenance is considered to become necessary. If the performance requirements can be described in terms of a critical degradation level it is possible to transform a dose-response function into a damage function. The approach assumes that maintenance is carried out after a given thickness of material has been lost. These critical thickness losses and the maintenance and repair costs associated with them are taken from the ExternE Methodology (EC, 1995) which also provides information on the underlying assumptions and uncertainties with this approach. To value these effects, repair/replacement costs of building components are used as a proxy estimate of economic damage.

Details are presented in the box below.

2.11.3 Visual impact

Visibility is one of the most obvious effects of urban air pollution. As figures in the case studies illustrate, the visual pollution in the cities of developing countries can be extreme, with urban smog similar to those in Europe and the US found several decades ago.

Visibility, perhaps more clearly expressed as 'visual range', is a function of the rate of light extinction through scattering and absorption. A number of pollutants have potential effects on visibility including primary particles, NO_2 and sulphate and nitrate aerosols.

Assessing impacts to buildings

A number of exposure-response functions exist in the literature for evaluating the above material damages from SO_2 (e.g. Lipfert 1987, 1989; Butlin *et al*, 1992a/b, 1994). However, a more recent set of functions have been produced by the UNECE Integrated Collaborative Programme (ICP) (Tiblad et al, 1998) which has looked at atmospheric corrosion of materials across Europe using a uniform experimental protocol. This is based on an 8-year field exposure programme that was started in September 1987 and involved 39 exposure sites in 12 European countries and in the United States and Canada. Functions are presented below for unsheltered materials.

Limestone

$R = t^{0.96}(2.7[SO_2]^{0.48} \exp\{-0.018T\} + 0.019Rain[H^+])$

Sandstone

$R = t^{0.91}(2.0[SO_2]^{0.52} + 0.028Rain[H^+])$ $T<10°C$

$R = t^{0.91}(2.0[SO_2]^{0.52} \exp\{-0.013(T-10)\} + 0.028Rain[H^+])$ $T>10°C$

Zinc

$ML = 1.35[SO_2]^{0.22}\exp\{0.018Rh + 0.062(T-10) \}t^{0.85} + 0.029Rain[H^+]t$ $T<10°C$

$ML = 1.35[SO_2]^{0.22}\exp\{0.018Rh - 0.021(T-10) \}t^{0.85} + 0.029Rain[H^+]t$ $T>10°C$

Coil coated galv. steel with alkyd melamine

$(10\text{-}ASTM) = t^{0.43}(0.0084[SO_2] + 0.015Rh + 0.040(T-10) + 0.00082Rain)$ $T<10°C$

$(10\text{-}ASTM) = t^{0.43}(0.0084[SO_2] + 0.015Rh - 0.064(T-10) + 0.00082Rain)$ $T>10°C$

where R is the surface recession in µm, ML is the mass loss in g/m^2 and ASTM is a rating from 1 to 10 where ASTM=10 corresponds to an undamaged material.

The additional parameters are temperature, relative humidity and exposure time. All parameters are expressed as annual averages.

t = Time 1-8 year
T = Temperature 2-19 °C
Rh = Relative humidity 56-86 %
$[SO_2]$ =SO_2 concentration 1-83 $\mu g/m^3$
Rain = Rainfall 327-2144 mm
[H +] = H + concentration 0.0006-0.13 mg/

Pollutant effects on visibility are regarded as a serious issue in the USA, though they have not received much attention in Europe, where visibility is not perceived to be a major issue. This perhaps reflects the fact that although there have been periods when air pollution has a clear and dramatic effect on visibility, such events are rare. Quantification of both the change in visual range and valuation of the loss of amenity through reduction in visibility is possible, though totally reliant on data from the USA. Holland *et al* (1998) used these data in analysis on behalf of the UNECE Task Force on Economic Aspects of Abatement Strategies and calculated substantial damages, exceeded only by effects on health. However, given the lack of concern over this issue in Europe, and restraints on the analysis (in particular relating to short term fluctuations in pollution levels) it was concluded that the results were not reliable. Certainly their application to developing countries would be controversial. The issue is thus identified here as being of possible significance, though it is not possible to make any clear statement about the relative magnitude of benefits from improved visibility compared to the other benefits discussed.

2.11.4 Crops, forests and natural ecosystems

Air pollution also impacts on crops, forests and natural ecosystems. Within an urban area, the proportion of land covered by crops or ecosystems will be low and therefore the issue is not as important for this guidance. However, the pollution from urban areas has very important impacts on these receptors from regional transport of air pollutants (especially for secondary pollutants). A discussion is therefore presented here.

Ozone is regarded as the main pollutant of concern with respect to crops in Europe and the USA. Quantification is possible through exposure response relationships that link air pollution concentrations with changes in yield, though indirect impacts could be more significant than the direct effects quantified in these methods. Ozone may also have impacts on forest and on other ecosystems. Some exposure-response function for the effects of ozone on trees have been developed, though the long lifetime of trees makes quantification of yield change far more uncertain than for crops, and economic assessment of change in timber yield is not feasible with any level of confidence.

Sulphur dioxide is also important for developing countries. SO_2 can also influence crop yield or quality. The effects of SO_2 can include changes to soil acidity (via deposition), crop fertilisation from deposition, and impacts on pests and diseases from ambient concentrations. It is not currently possible to quantify all of these effects.

The effects of SO_2 and secondary pollutants on ecosystems ranging from forests to freshwaters are well known, and have been the prime concern until recently in international negotiations on sulphur and nitrogen in Europe. The most notable is soil acidification, which leads to depletion of base cations and mobilisation of aluminium and has significant consequences for most types of soil life (including plants). Enhanced sulphate deposition also leads to an increase in nitrogen deposition through interaction with ammonia, with further problems in terms of acidification and nutrificiation. These effects are also being seen in areas of high coal use, notably in South East Asia, such as China.

Emissions of NO_x are known to be responsible for a range of impacts on ecosystems particularly through their contribution to acidification, eutrophication and the generation of tropospheric ozone. Similar issue exist to the assessment of SO_2. Nitrogen availability is very limited in many soils, and additional inputs are readily assimilated. However, this is not typically beneficial in natural and semi-natural ecosystems which have evolved to exist with limited N availability. Once N becomes more readily available, species that have a higher N demand typically invade, often reducing species richness. A number of interactions are also likely to exist that affect response to N deposition, for example, with frost, drought resistance and insect pests. Freshwater bodies are also sensitive to N deposition

Impacts can also arise from the effects of acidity on sensitive freshwater bodies. However, despite the large, well documented literature available on impacts, it is not currently possible to conduct an economic analysis of the effects of SO_2 and related secondary pollutants (sulphates and acidity) on forests, other terrestrial ecosystems and freshwaters with confidence. A robust analysis would require knowledge of specific effects (change in species richness, productivity, etc.) over extended time scales and appropriate models are not available. In consequence, predictive analysis in this field has almost solely followed the critical levels/critical loads concept (e.g. Amann *et al*, 1996; Posch *et al*, 1997; RGAR, 1997). There is not the same level of data in developing countries to assess these potentially impacts in a similar, way, though progress is being made through projects such as RAINS-ASIA. Initial analysis indicatess that the problems are potentially greater - recent estimates (World Bank, 1997) estimate the potential effects of crop and forest damage in China at $5 billion a year.

Assessing impacts on crops

The quantification of ozone damages to crops has been undertaken in the US and Europe. The approach uses a dose-response approach, linking these with land cover data and likely pollution levels (in terms of AOT40). In order to quantify effects, data is needed on agricultural production. A large number of laboratory experiments have clearly established that ozone, at ambient concentrations, has harmful effects on many plants and exposure-response functions have been derived.

However, the functions used are largely derived from experiments on a few cultivars under closely controlled laboratory conditions (single pollutant, particular exposure scenarios) and in which other factors of production (notably water) are controlled for growth. It is therefore questionable to what extent results reflect reality in the field, where response may be different for a number of reasons, including: sensitivities of different cultivars, interactions with other pollutants, adaptation to ozone impacts, and humidity and water availability. These issues are especially important in developing countries, where agriculture is less modernised. No account is taken of interactions with insect pests, climate etc., which may be as significant than any direct effects on yield

SO_2 has been shown to damage crops directly at high pollutant concentrations. At the ambient levels currently present in many part of Europe these impacts are likely to be very low and may in fact be beneficial. However, for many developing countries the levels of SO_2 and acidification will mean that impacts occur. These direct effects can be quantified using a dose-response approach linking pollution levels with crop yields.

Where quantification of crop losses can be undertaken, prices from United Nations Food and Agriculture Organisation (FAO, 1994) can be used for valuation. These represent world prices, which are a closer approximation to real resource costs than local prices.

2.12 Climate Change

This study concentrates on urban air pollution. However, given the potential importance of climate change, it is prudent to report on the potential environmental effects of greenhouse gas emissions and to make sure these effects are considered alongside other environmental effects when looking at measures to improve urban air quality.

To date, most studies which assess the effects of climate change have been performed in two stages. The first of these is assessing the contribution of emissions to global warming, and the second estimating the consequences of estimated warming. Given the global nature of climate change via the long atmospheric residence time of greenhouse gases, there is no need for spatial analysis and the contribution of emissions to overall greenhouse gas concentrations can be simply linked using aggregate unit impacts (i.e., $/tonne). The latter can include cost estimates, based on either likely damage costs or on mitigation costs to avoid impacts. The former centre on predicted damage costs for key areas (e.g. human health, agriculture, water, sea level rise, extreme events, ecosystems and unexpected events) using simple, but robust models of the physical, social and economic impacts of changes in temperature, rainfall and sea level. Damage assessment is then undertaken using different scenarios and discount rates.

Interestingly, although climate change is a truly global effect, the impacts will not be experienced equally over the whole world. Recent evidence shows that developing countries are likely to be dis-proportionately affected by climate change as there are important differences in the effects between world regions.

The IPCC (1996) reported the range of possible damage costs from climate change (based on the literature) from $5-125 per tonne of carbon. The numbers vary according to the underlying assumptions (including the valuation of human life) and the discount rate used. More recent and sophisticated studies have derived values of $80 per tonne of carbon (e.g. ExternE, 1998, based on a 3% discount rate and assuming equity weighting) though the use of a single estimate is misleading. However, This value (equivalent to around £15/tonne CO_2) is very similar estimates of the marginal abatement costs if the signatories to the Kyoto protocol are considered as a whole.

We stress however that the valuation of climate change is problematic, raising important intra- and inter generational equity issues, as well as global equity issues. As a result, the available estimates of the costs of climate change are neither complete nor accurate, and a considerable range is attached to any numbers produced. What is more, the values constantly change and need to be kept updated on a regular basis. In using such numbers, because of the higher uncertainty attached to climate change effects and valuation, we recommend that the values are presented separately to other impact categories, in recognition of the different level of confidence attached to these numbers.

Climate change

There is an increasing number of studies on the potential size of the impact from climate change. The Working Groups of the Intergovernmental Panel on Climate Change (IPCC) have extensively reviewed the impacts of climate change on human health and natural systems (WG II) and the economic assessment of these impacts (WG III). The external cost literature assesses damages due to a level of global warming resulting from an equivalent doubling of pre-industrial carbon dioxide concentrations ($2xCO_2$); they therefore have to be scaled to determine the impacts of individual studies. Earlier studies (e.g. Cline, 1992; Fankhauser, 1993; Hohmeyer and Gärtner, 1992; Tol, 1995) estimated the impacts from warming levels due to an equivalent doubling of pre-industrial carbon dioxide concentrations, to be of the order of 1.5-2% of gross world production, though while OECD countries would lose 1-1.5% of GDP, developing countries would lose 2-9% (Fankhauser and Tol, 1996). These values include both adaptation costs (such as coastal protection and changes in space heating, etc.) and residual damages, (loss of wetland, etc.).

Despite these improvements, the valuation of global warming impacts is still extremely problematic for three main reasons:

- The incompleteness of detailed impacts studies;
- The large uncertainties in estimates of impacts;
- The likelihood of significant interactions between different impact categories which are usually considered separately (e.g. agriculture and water resources).

The most important uncertainty of any valuation analysis of global warming impacts is the future of world development over the hundreds of years in which impacts are anticipated. The capacity of society to deal with the changes resulting from climate change will depend critically on levels of social and economic development. For this reason all estimates of climate change damages should be treated with caution, especially where the underlying scenario is not specified (European Commission, 1995).

2.13 Conclusions

This Chapter presents a brief review of urban energy-related emissions and their environmental effects.

Energy related emissions arising from industry, transport and the domestic sectors are typically the dominant cause of poor air quality in urban areas. The emissions from the use of fossil fuels in all of the above sectors release a number of common pollutants affecting local and regional air concentrations. However, different sectors affect air quality differently due to the height and nature of the emissions they release, as well as the balance of different pollutants.

Urban air quality has a number of important environmental impacts. These include impacts on human health, buildings, and amenity. Urban air quality also impacts on crops, forests and natural ecosystems through regional pollution. The greenhouse gas emissions from energy-use also have global effects through the potential impacts of climate change.

Major advances over recent years now mean it is possible to quantify these health and environmental effects and the chapter provides guidance on the methodology to do this. The recommended approach follows a number of steps, namely:

- To quantify the emissions from the pollutant source;
- To assess the impact on air pollution concentrations in the surrounding area from these emissions (using air pollution dispersion models);
- To assess the population or receptors exposed to these pollution increases;
- To use exposure-response functions that link pollution increments to health or damage endpoints.

This step by step approach is known as a bottom-up or impact pathway approach. The approach takes account of the location of emissions and receptors. It can therefore differentiate between the relative effects of emissions on air quality from ground level releases, such as transport and high-level stack emissions.

There is an additional final step that can be undertaken using this approach: to convert the environmental effects into economic units. This allows the consideration of different environmental effects on different receptors in equivalent terms. It also provides a means for incorporating environmental decisions alongside traditional economic criteria when considering, for example, how to prioritise different options (the subject of Chapter 4).

These environmental costs are not included in the costs paid directly by energy users. For this reason, they are known as ‘external costs’ or ‘externalities’. There is a recognition that the monetary evaluation of environmental impacts needs to be incorporated in appraisal and decision support tools.

Valuing environmental damages in this way remains somewhat controversial. However, objectors ignore the simple fact that measures for improving the environment cost money. Monetisation provides a mechanism for comparing the benefits to be gained from alternative environmental improvement strategies, and hence a framework for deciding how best to spend the money that is available. It is also a reasonably transparent process, explicitly demonstrating the weights attached to effects considered. In the long-run, this should facilitate a more objective debate on pollution control than has hitherto been possible

The impact pathway approach with economic valuation of environmental effects has been widely used by the European Commission and countries such as the UK and the US in recent years. Applications include the use of the approach to provide policy makers with advice on issues such as air quality policy, and development of transport, waste and energy strategy.

The study has reviewed and produced guidance on quantifying and valuing health and non-health effects for ambient urban air quality, based on review of the literature. Health impacts are identified as the most important economic effect of poor air quality, with the pollutant PM_{10} as the major cause of concern. Uncertainties do exist in the use of the techniques recommended here, and to help communicate this, impacts have been given uncertainty rankings to allow any user to undertake sensitivity analysis. There is also an issue of transferability between Western studies and developing countries. This issue is relevant both for some of the health effects, notably the lack of information on the transferability of chronic health effects, and for the monetary valuation of all health effects.

The chapter also provides a very brief review of the economic costs of greenhouse gas emissions. Monetary values have been recommended for possible use in economic frameworks based on the central values that exist in the literature, though we stress that the valuation of climate change is more uncertain than other areas and recommend that associated values are presented separately to other impact categories.

It is stressed that most of the relationships and methods proposed in this chapter have been derived from studies in developed countries. This is not ideal, and it will inevitably lead to some bias, but is unavoidable given the relatively few studies undertaken in developing countries. The need for more research studies in developing countries, in order to bridge this gap, is highlighted as a priority area.

One area where this is particularly apparent is with the quantification of the health effects of indoor pollution. It is likely that there are major health effects from the use of solid fuels in the homes of urban areas. These health effects are likely to be additional to the effects from ambient air pollution identified in the guidance and these should be included (additionally) in the analysis of air pollution in urban areas. At present the best method to do this draws on the approach used for ambient air pollution, though this is not ideal. We highlight the identification of methods for quantifying indoor air pollution from domestic energy as a research priority from this review.

As a final note, it is highlighted that the field of environmental economics is a rapidly advancing. All the underlying relationships and values recommended maybe subject to change and need to be kept updated on a regular basis. We also conclude that greater steps are needed to ensure consistent methods are used internationally for assessing these effects, as well as their associated uncertainties.

3 Air Pollution and Poverty

3.1 Introduction

This Chapter summarises a literature review of air quality and its impact on poor and vulnerable groups. Of course, for people living in poverty the most pressing priority is the satisfaction of the basic human needs such as shelter, availability of potable water, sanitation, access to health services and education, rather than good air quality. However, there is strong evidence that the poor suffer dis-proportionately from the effects of air pollution, and that poor air quality itself actually exacerbates poverty. These factors are particularly important as it is estimated that by 2000, approximately one half of the poorest people in the developing world will be living in urban areas.

The review here builds on two previous DFID studies. This first was commissioned by the DFID Engineering KaR programme on ‘Energy Provision to the Urban Poor’ (R7182). This work compiled case studies from Kenya, India, Mali, Peru and South Africa. The synthesis of these found that:

- The poor pay the highest price for useful energy because they are dependent on low-grade fuels that convert at very low efficiencies;
- This also has a significant impact on the health of the households, particularly children;
- Small-scale enterprises are vulnerable to limited availability of energy and changes in its cost;
- A positive impact on the poor would result from improving access to energy efficient equipment and more reliable supplies of better fuel.

The second study ‘Energy Efficiency and Poverty Alleviation’ (R7222) confirmed that there could be poverty benefits arising from improved energy efficiency in general (both domestic and industrial). This study tested its findings in urban India and concluded “there is a need to put energy on the urban planning agenda”.

3.2 The link between Poverty and Areas of High Pollution

A number of studies show that poorer areas tend to have higher concentrations of air pollution. These effects are seen at two levels, for specific areas within any individual city and also between different cities.

Firstly, within any city or urban area, the less affluent districts tend to be concentrated in areas with a higher density of roads, traffic and industry and so have higher levels of pollution. This primarily occurs because the urban poor are forced to make trade-offs between affordable housing and environmental safety and protection. Property prices will be cheaper in areas with a greater concentatrion of roads, industrial activity, etc. There are, however, other reasons for the link. The poor are less concerned with the impacts of air pollution and less well informed about its impacts. They are therefore less likely to resist, or apply less pressure as a community, to the developments of new roads, factories, etc. nearby, as well as abatement decisions on existing plant or road traffic management improvements. As a result, richer, better informed and more educated communities will influence decisions made by regulators and plant operators more effectively through campaigning, better use of the media, and the organisation of influential environmental groups.

Secondly, economic wealth is linked to air pollution at a city level. Poorer cities have higher levels of pollution than richer ones. This relationships is perhaps counteriniutive – richer areas will have more industrial production and so might be expected to have higher air pollution. However, air pollution monitoring in different cities has shown that as wages increase, pollution levels fall (World Bank, 1997). This trend arises because economic wealth is usually accompanied by increasingly informed citizens, more skilled workers, more efficient processes, and stricter (or more enforcement of) environmental legislation. Moreover, as areas develop economically, higher income goods are produced whose manufacture produces lower pollution and greater levels of secondary and tertiary industries move into the area. Such trends can be seen clearly in the south-east Asian countries and increasingly in China (see case study).

Interestingly, the relationships between poverty and air pollution are not confined to developing countries – they are also widespread in Europe and the US (e.g. see Watkiss et al, 2000). The links between air pollution and poverty are often highlighted in studies into 'environmental justice' and show that everything from landfill waste sties, to polluting industry are disproportionately located near poor and minority communities.

However, there is another important factor that must be noted in addition to the above discussion. The relationships described above relate only to ambient air pollution (i.e. outside air quality). There is also a direct link between poverty and indoor air pollution. Indeed, it is likely that in terms of exposure levels, and subsequent health effects, indoor air pollution is the dominant problem for the urban poor.

3.3 Poverty and Energy-Use

Low energy consumption and the lack of available energy services correlates closely with many poverty indicators. However, while it is tempting to associate poverty with inadequate energy consumption, there is another factor that is relevant: the poor typically use energy with inefficient technologies and with poor quality fuels.

These factors have important implications for air quality. The use of poor quality fuel and low efficiency combustion will produce higher emissions and more air pollution per unit of fuel burned. As a result, ambient air quality problems, which are often higher in poorer areas due to neighbouring roads and industry, are often further exacerbated from the use of low grade fuels and inefficient technologies for domestic energy supply. The problem also applies to local small-scale industry, including community led projects. For both these sources, emissions are typically released at ground-level in the immediate area of the urban population. They therefore lead to very high population weighted exposure levels.

However, a greater problem in these areas relates to indoor air quality. The use of solid fuels in the home causes very high levels of indoor air pollution. The greatest problems arise from the use of coal, especially low grade coal, though wood burning is also a problem. These problems are often exacerbated by the lack of good ventilation systems and so indoor exposure to high levels of pollution is common, especially in wintertime.

The case study in the Republic of South Africa (appendix 2) illustrates the scale of these problems. Low-grade coal is used in inefficient stoves (often converted oil drums and open fires)in urban townships. In addition, many of the houses that use this coal have no chimneys or ventilation. The levels of particles and SO_2 concentrations found in homes burning these fuels typcially exceed WHO air quality standards by orders of magnitude. As a result, the mortality rate for acute respiratory tract infections among children in these areas are orders of magnitude higher than for children in Western Europe (Britton, 1998).

The problem of indoor air pollution is likely to dominate the health burden on the urban poor in most colder countries, in the cases where solid fuel is used in the home for space heating. It also affects specific vulnerable groups dis-proportionately (see later section). For example, over half the urban population use of coal for winter heat in the RSA. Not surprisingly, the introduction of low-smoke fuels within townships has been estimated to have the single largest potential for improvement of health from air pollution in urban areas (Van Niekerk and Simpson, 1997).

3.4 Poverty and Transport

Transport is a key aspect in economic development. However, as with many other issues, the urban poor are disproportionately affected by inefficient transport provision. Many of these issues are wider than energy-use and are summarised in the box below. There are, however, a number of issues, which are relevant specifically to energy-use.

Poverty and Transport

Transport can reduce absolute poverty by increasing economic efficiency – in effect by lowering costs and prices and enhancing opportunities. It also is key in offering access to employment and to other services. However, the access to these benefits and to transportation more generally is not shared equally between rich and poor. The problem is particularly acute in rural areas, though even within the urban context there are problems.

Access to job opportunities in urban areas is necessary for the poor to participate in most income-earning activities. In most cities, low-income households inevitably rely on public transport. In severe cases this may exclude them from employment or other opportunities (social or economic exclusion), for example compared to people with private transport. In most cases they may be subject to inequalities with respect journey length and time, journey conditions and cost.

In many developing countries, the urban poor are concentrated on the periphery of urban areas, which is far from their workplaces. Long work journeys (2.5 hours/day) to the urban centres, often by slow and uncomfortable means, with modal transfers is a common problem. One answer would be to move closer to areas of work. However, residential relocation is often very difficult for the poor due to high moving costs and lack of affordable alternative locations (Gannon and Liu, 1997).

Travel conditions are often poor, with huge overcrowding in peak times due to a shortage of capacity. For example, average peak hour loading of trains in Greater Mumbai (India) is in excess of 4,000 passengers per train compared to a “design capacity” of about 1,800 per train and “crush load capacity” of 2,600 per train (World Bank, 1999b). Buses also tend to be overcrowded.

Finally, the cost of public transport (especially better quality services) may be high. Moreover, the urban poor have to pay a greater proportion of any income on transport (up to 20% of income). As a result, affordable public transport can have an immediate impact on the personal welfare of the urban poor (World Bank, 1994c). In cases where transport costs are high, this can lead to geographical, social, and economic isolation for the poor. Indeed poorer neighbourhoods often suffer from the lack of affordable access to public transit or physical and regulatory barriers to entry by informal transport services (Gannon and Liu, 1997). Because of these factors, the ability of the poor to obtain employment is highly dependent on the costs and availability of public transport.

In many developing countries, there has been huge growth in private motor vehicle ownership as incomes have increased. However, the poor cannot afford to buy cars, and when they do so, they tend to be old and polluting vehicles. This in turn leads to higher emissions in these residential areas. This may be compounded by the use of older public transport vehicles to provide transport services that supply these poorer areas. Indeed, poorer areas are generally the last to be served by newer, cleaner vehicles and modes.

There is one issue that warrants special attention with respect to transport – lead emissions from petrol. The emission of lead is a very significant problem in many developing countries, even though countries are increasingly banning it's use. Leaded petrol is believed to account for 90% of all lead emissions to the atmosphere in many cities in the developing world (Pearce, 1996) and as the previous chapter describes, damages the mental abilities of children, as well as causing other health problems.

3.5 Air Pollution and Vulnerable Groups

There is growing evidence that the impacts of air pollution fall dis-proportionately on the poor and specifically on certain vulnerable groups (children and the elderly). Air quality exposure may also have strong differences according to gender.

As the previous Chapter showed, air pollution can lead to respiratory illness. As well as being exposed to higher levels of air pollution, both indoors and outdoors, the poor are also more likely to be affected by air-polluted illness because of pre-disposing factors. Oviously the general health state of individuals will be a major factor in pre-diposition to disease and so areas which have lower quality diets, lower levels of sanitation, etc. are likely to be more at risk from these conditions. With respect to these additional factors, it is the elderly and children that are most at risk. Indeed, studies have shown that the incidence of respiratory disease amongst children in the urban areas of developing countries is orders of magnitude higher than in Western Europe.

In developed countries, many of the health impacts of air pollution tend to occur in the old. This is also true in developing countries, though as presented in the previous chapter, it also affects the young. For example, an air pollution study comparing Santiago (which has major air pollution) with Los Andes (which does not) found that children in Santiago suffered from a 25% higher incidence of coughing fits, a 12% greater incidence of hoarseness in the throat, and an 9% greater incidence of nocturnal respiratory symptoms (IIEC, 1997). The study showed that asthma was about 1.5 times more common and pneumonia 2.8 times more common in Santiago and estimated 8% of one-year olds in Santiago had blood lead levels higher than the WHO recommended level of 10 micrograms per decilitre.

Health related air pollution effects are also greater in the poor because of medical access. The poor are likely to have less access to medical care, because they cannot afford it. Moreover, illness can reduce the ability to work and will reduce earning ability and income. Both of these effects will add add extra economic penalities to people who can afford them least.

Finally, air polution can impact on certain groups more because of exposure patterns. This can lead to higher air pollution exposure for certin social or economic groups.

Exposure will also be affected by employment, and travel to it. The urban poor are likely to spend a greater proportion of their time travelling along polluted streets. They may work outside, close to roads, or in poorly ventilated factories or industry.

The combination of these factors have been shown in studies. In Indonesia studies have shown that slum dwellers had the highest measured levels of lead (reflecting transport emissions) in their blood, followed by street vendors and bemo (mini-bus) drivers. Also, a recent survey of household-level environmental problems in Jakarta, Indonesia, found that respiratory disease was present in 33% of "low" socio-economic status households, as compared to 25% of "middle" and 22% of "high" socio-economic status households (Surjadi, 1993).

Poorer families will be subject to the additional indoor air pollution concentrations that arise from domestic use of biomass or low quality coal. There is also an exposure issue by age and gender. Within the family, the length of time spent in the home will vary, with women, children and the elderly spending greater lengths of time inside (because of domestic tasks and because of mobility issues). This is reflected in the very high levels of respiratory illness seen in these groups.

Transport and Vulnerable Groups

There are a number of specific issues with transport concerning gender and vulnerable groups. These problems are particularly acute in rural areas, though they also exist in the urban areas of developing countries.

The effects are greatest in the context of poverty. The lower the income of a household the more probable it is that women will experience greater transport deprivation as compared to men. This may take the form of lack of access to transport (Grieco and Turner, 1997). For women it can often mean the use of inferior modes of transport, as well as longer journey times. In exceptional cases, it may take the form of customary or legal constraints on women's right to travel or to use a particular transport mode. As women often spend more of the time on activities that require transport, these effects (and the issues raised on journey conditions and time) raise important inequality issues.

In countries or areas that are more developed, other issues emerge, especially for countries with increased car dependency. Women and children, and others that do not have access to motor vehicles such as the elderly and the disabled, are often particularly isolated, aggravating social and economic polarisation. Moreover, the lifestyle changes induced by car dependency typically force women to spend more time in car travel, chauffeuring children or elderly relatives, shopping and commuting to and from work (Fletcher, 1999).

3.6 Conclusions

This Chapter briefly reviews the literature concerning air quality impacts on poor and vulnerable groups. Of course, for people living in poverty the most pressing priority is the satisfaction of the basic human needs such as shelter, availability of potable water, sanitation, etc. However, the review shows that the poor tend to suffer from the effects of air pollution dis-proportionately, and that poor air quality itself actually exacerbates poverty.

These effects occur firstly because of location. Within most cities, the less affluent districts tend to be concentrated in areas with a higher density of roads, traffic and industry. Moreover, because the poor are less concerned with the impacts of air pollution and less well informed about its impacts, less controls over pollution or new plant are introduced in these areas. The effect is also seen between cities: areas at a higher level of economic development tend to have lower air pollution due greater levels of secondary and tertiary industries and higher efficiency and greater pollution controls on primary industry.

Secondly, air pollution problems are compounded for the poor as they typically use energy very inefficiently, with the use of low efficiency technology and poor quality fuel. Elevated ambient air concentrations are typically found in areas where solid fuels are used in the home for domestic heating. However, a much greater problem for these areas arises from indoor air pollution. These problems are often exacerbated by the lack of good ventilation systems. In cases where solid fuels are used extensively for domestic space heating (e.g. countries with colder winters), indoor air pollution is likely to dominate the health effects on the urban poor.

As well as being exposed to higher levels of air pollution, the poor are also more likely to be affected by air-polluted illness because of pre-disposing factors. Moreover, for these impacts, it is the elderly and children that are most at risk. Air polution can also impact on certain groups more because of exposure patterns. This can lead to higher air pollution exposure for specific social or economic groups. For example, within the family, the length of time spent in the highly polluted home will vary, with women, children and the elderly spending greater lengths of time in these conditions. Air pollution related illness also adds additional financial burden from medical care (if affordable) or a reduction in the ability to work (earning ability) from air pollution related illness.

Given these effects, we conclude that air pollution measures that aim to address energy use for the poor are likely to have very large benefits in improving air quality, and in turn reducing associated health and economic impacts. Thus, reducing the impact of urban energy use is a key aspect in the development process . However, it is necessary to target resources towards the most efficient ways of improving air quality.

4 Options for Reducing Energy-Related Emissions

4.1 Introduction

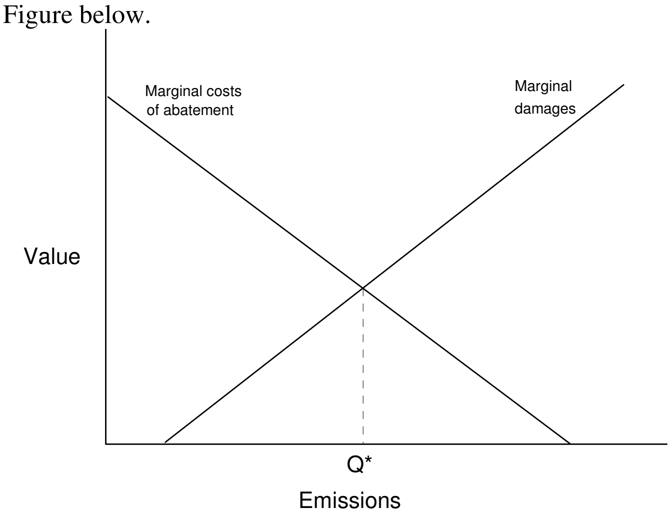
Given the importance of energy related pollution in the cities of developing countries, the next step of the guidance is to review energy-related measures that can be used to improve air quality and to assess their potential effectiveness. Different options or measures for improving air quality have traditionally been evaluated in terms of their 'cost-effectiveness' (see section 4.3). This information is then used to help set air quality management, planning and strategy. This chapter sets out to show how this analysis can be extended to combine cost information with environmental data from the second chapter, to assess measures in terms of their relative costs and benefits. It sets out other important criteria that are often excluded from strategies, such as socio-economic effects, climate change impacts, acceptability, and any specific benefits or dis-benefits on the poor, in recognition of the importance of these criteria in producing balanced, equitable and holistic programmes for addressing urban air quality.

4.2 Air Quality Management

The sequence of assessing emissions, air pollution concentrations and options for improving urban air quality is collectively known as air quality management and strategy. An air quality management plan seeks to implement a set of measures to reduce air pollution and environmental impacts in the most cost-effective way. Usually the plan is targeted on air quality standards or objectives (e.g. WHO guidance), though from a purely economic standpoint, the plan should be implemented to the economically optimal level (see box below).

Economic Concepts

From the perspective of society as a whole, the objective of an air quality plan designed to improve air quality and so reduce its environmental costs should be to reach an economically optimum position. Having assessed the costs of different measures and compared against the benefits they achieve, emissions should be reduced to the point where the marginal costs of implementing a measure are equal to the marginal economic benefit it achieves, shown in the Figure below.



Definition of the socially optimal level of polluting activity, represented by the line Q*E. At this level the marginal costs of abatement are equal to the marginal costs of damage.

Air quality management involves a series of steps. They involve the derivation of an emissions inventory to characterise sources of pollution, and the use of this information with air dispersion models to predict the resulting air quality concentrations. These activities are usually linked to an air quality monitoring programme, put in place to measure ambient concentrations and help verify the modelling.

Once the effectiveness of different measures is assessed, they can be ranked and prioritised. The air quality plan is then implemented selecting the most appropriate measure or combinations of measures to achieve the necessary air quality targets for least cost. These steps are summarised below.

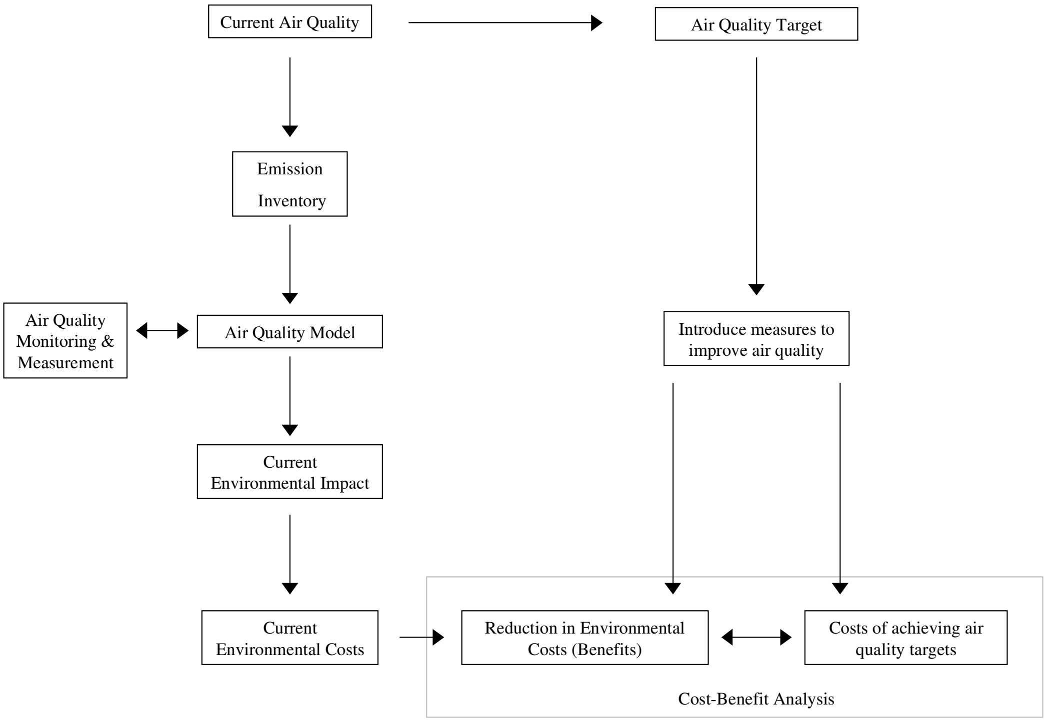


Figure 3. The steps in Air Quality Management

The steps involved in air pollution monitoring, assessment and emission inventories are large subjects in their own right. Further information on these issues and guidelines are included in the WHO air quality management guidelines (http://www.who.int/peh/air/airindex.htm) and in the Global Environment Monitoring System GEMS/AIR information products (http://www.who.int/peh/air/gemsair2.htm) which include relevant handbooks. Information can also be found on the US Ambient Monitoring Technology Information Centre website (http://www.epa.gov/ttn/amtic/). This contains information and files on ambient air quality monitoring programs, details on monitoring methods, relevant documents and articles, information on air quality trends. Finally, information is also available from the URBAIR guidebook (WB, 1999) and web site.

4.3 Cost-Effectiveness

4.3.1 single pollutants

In order to assess different measures for improving air quality, it is important to assess the costs of implementing a measure and the likely air quality improvements it is likely to achieve, i.e. their cost-effectiveness. The cost-effectiveness of a measure is usually expressed in terms of the costs to reduce one tonne of emissions or to improve air quality by 1 $\mu g/m^3$. By evaluating options in this way, it is then possible to rank them in order of cost-effectiveness. In terms of implementing an air quality action plan or programme, those measures which are most cost-effective should be introduced first, and subsequent measures introduced until the target objectives achieved (or until is economically sensible to continue). This ensures achievement of the target air quality levels at least cost.

Well-established methods exist for assessing the costs of measures. For example, guidance on assessment of costs have been produced by the European Environment Agency. A summary of these guidelines is presented in the box below and can be found at http://www.eea.eu.int/. Cost guidance document is also available from US EPA information sources, such as http://www.epa.gov/ttn/ecas/costguid.html

Cost-Effectiveness

The EEA summary guidelines ('Guidelines for defining and documenting data on costs of possible environmental protection measures', EEA 2000) are:

- Pollutant definitions and assumptions regarding scope of pollutant categories should always be given wherever there is any possibility of ambiguity.
- Sufficient detail of the pollution source should be given to enable comparison with similar processes and to avoid ambiguity. It is recommended that published source sector classifications are used wherever possible.
- Sufficient detail of the environmental protection measure should be given to avoid ambiguity, to define its performance characteristics, and to clarify any special circumstances limiting applicability of the measure.
- It is essential that reported costs are defined: what is included, what is excluded, how they have been attributed or apportioned. It is recommended that costs are also explained in physical terms such as quantity of materials, and as unit prices.
- As a minimum, all data should have a background discussion of the key uncertainties related to the data.
- The year in which the following data apply should always be given:
  - 1) cost data; 2) currency exchange rates; 3) data describing control technologies (efficiency, applicability) and process technologies; 4) emissions to the environment.
- The sources and origins of all data should be recorded as precisely as possible so that data may be traced at a later date if necessary.
- As a minimum, any discount/interest rates used should be recorded.
- If cost data are adjusted for inflation or changes in price through time, then the method used should be recorded and any index used should be recorded and referenced.
- If determining annual cost data, the approach that has been used to derive the annual costs should be recorded, along with all underlying assumptions.

The guidance recommends all cost estimates are presented in equivalent terms, usually equivalent annual costs, with everything adjusted to the same year and discount rates, and the cost stream annualised, using formula such as:

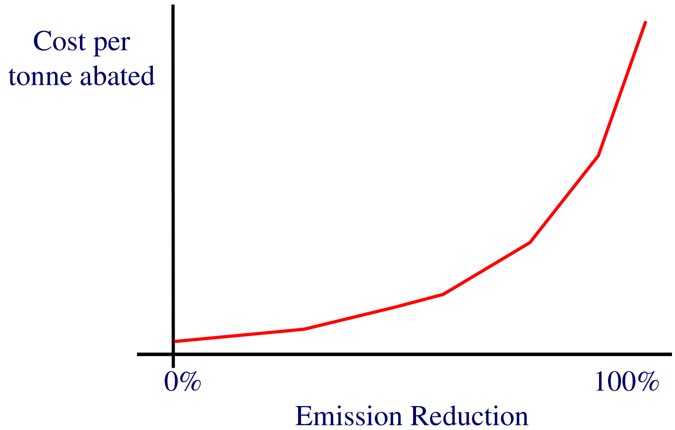
$$\mathrm{PVC}_0^k = \sum_{t=0}^{\mathrm{T}^k} \left[\mathrm{NRC}_t^k + \mathrm{ERC}_t^k + \mathrm{NERC}_t^k\right] \circ \left[1 + r\right]^{-t}$$ where:

PVC the present value of the total cost stream for environmental protection measure *k* in year zero,
NRC the non-recurring cost of environmental protection measure *k* in period *t*,
ERC the energy recurring costs to operate environmental protection measure *k* in period *t*,
NERC the non-energy recurring costs to operate environmental protection measure *k* in period *t*,
t, the operating life of environmental protection measure *k*, and
r = the appropriate discount rate.

The use of this approach ensures cost collection and assessment is consistent, so that when considering the costs of measures from diverse sources or in different sectors, information is expressed in equivalent terms. This includes taking into account when the cost information was compiled, whether the costs are discounted over time, and what assumptions are included in the estimates with respect to measure or scheme lifetime.

Costs are usually expressed in terms of an equivalent annual cost (or annualised cost), so that differences in terms of lifetime can be incorporated in the comparison. These equivalent annual costs can then be compared to the annual emissions reductions. When considered as part of the air quality management programme, the use of a dispersion model (see figure above) can be used to calculate the change in daily or annual $\mu g/m^3$ concentration achieved by the measure. This approach is preferable, since this allows consideration of the source of the emission (e.g. ground level)

The combination of these data allows ranking of options according to costs per tonne abated, or costs per $\mu g/m^3$. The cost-effectiveness information is often expressed in cost curves (e.g. as in the generic figure below). These typically show that the costs of pollution abatement rise exponentially, i.e. that improvements in air quality are initially low cost high return, but that as more and more measures are introduced, costs to achieve pollution reductions increase (i.e. diminishing returns). Given the status of technology, air pollution control, etc., in most developing countries, major improvements in air quality should be possible at relatively low cost, though even in the US and Europe low cost improvements are often possible through, for example, energy efficiency measures.

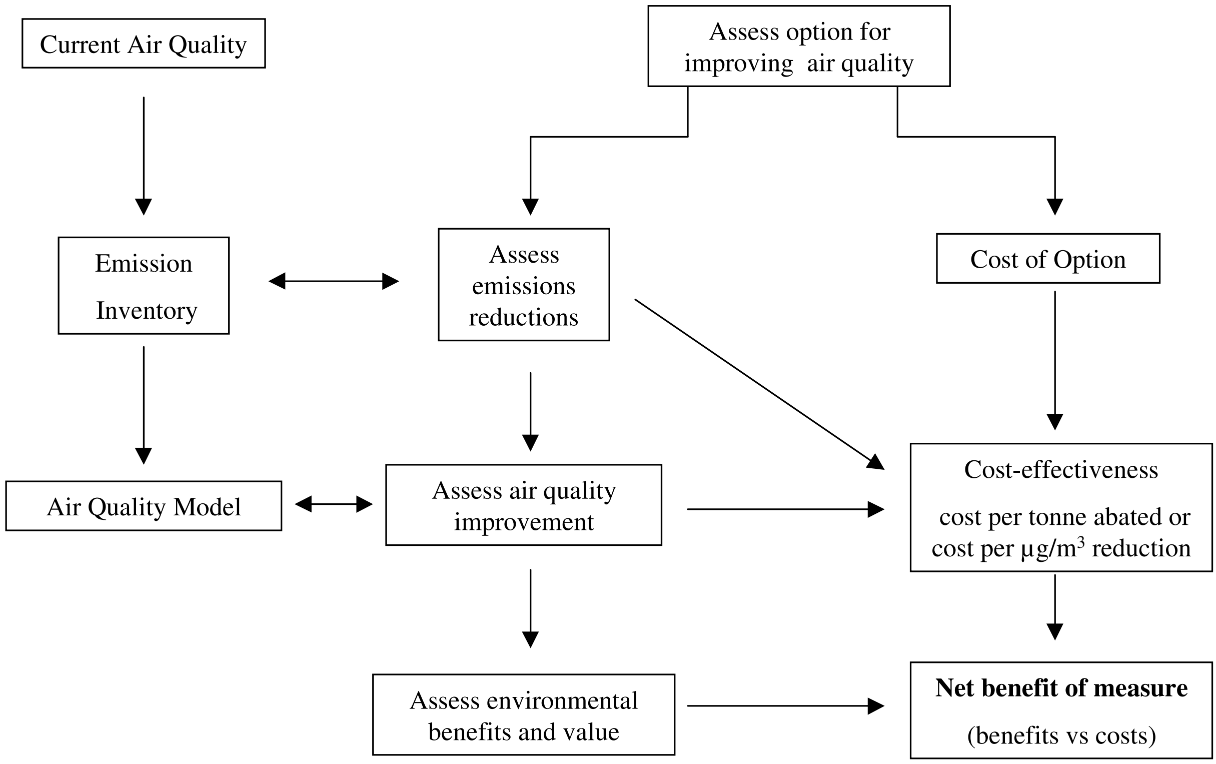


4.3.2 Multiple pollutants

There is, however, an issue that arises with the use of metrics such as cost per tonne abated, or cost per air pollution improvement. The aim of air quality improvement is to improve overall air quality, i.e. for all pollutants. Moreover, many measures or options will impact on more than one pollutant, for example measures that affect fuel efficiency for industrial energy efficiency will lead to benefits for all pollutants, whereas specific abatement technologies may only be directed at one particular pollutant. This creates a problem in ranking measures that have cross-pollutant effects. Moreover, assessment of $\mu g/m^3$ improvements alone fails to take into account the real levels of benefits. Measures which address ground level pollution emissions in areas of high population density will have much greater environmental benefits (by reducing the population weighted exposure levels) than high stack emissions in industrial sites located on a cities outskirts.

The solution to both these problems is through the use of the economic estimates of air pollution benefits. Ideally the dispersion models should be run with the proposed measure in place and the improvement in air quality assessed. This can be extended to asses the population weighted improvement, which can be used in turn to calculate the net environmental benefits (in monetary terms) from the measure, using the approach in Chapter 2. By progressing from air quality improvements to environmental benefits in monetary units, effects across pollutants can be summed to give the overall cost-effectiveness of a measure, i.e. the net cost (costs of implementation against environmental economic benefit).

Summarising, this leads to the following analysis for each option, shown in the figure below. Options can then prioritised in order of net cost-benefit.



This method provides a more efficient way of tackling air quality and the environmental effects it leads to. Measures are prioritised such that those that achieve the greater economic benefits are introduced first, though because environmental effects are internalised in these cost calculations, this also produces the optimum ranking with respect to reducing environmental impacts.

Expressing different measures in this way allows direct comparison of measures. More importantly it allows prioritisation of measures and should provide the basis for developing a cost-effective action plan. In drawing up the measures to be included in an action plan, the measures that achieve greatest air quality improvements for least cost should be included first, and then progressively more expensive measures added until the target air quality improvement is achieved.

However, there are a number of issues that remain. Firstly, the above analysis is based only on local air quality: other potential environmental effects are excluded. Secondly, it only assesses the direct economic costs of measures – indirect effects are often also important. Finally, it provides the optimum plan in terms of economic efficiency. However, from the perspective of society and its development, there are other important criteria, not least the fact that programmes should be fair and equitable and should address social-economic considerations. These other criteria are extremely important and should be considered in producing a balanced air quality management programme. They are discussed in turn below along with ways they can be included in assessments of options alongside traditional economic criteria. On this basis, the results of the analysis can be regarded as information that can usefully inform decision makers, but which, on its own, does not completely define the correct solution.

4.4 Other Environmental Effects

In assessing air quality measures and in drawing up air quality strategies, there is often a failure to address other environmental effects of measures, where these exist. There are two key areas where measures to address local air quality may have a detrimental effect on other categories of environmental impact. These are noise and climate change.

The issue of noise is most important for transport based measures. Any measures which impact on transport volume or speeds will affect noise, because of the speed dependent nature of transport noise (noise from vehicles is a combination of engine noise and tyre-road noise). It is possible to calculate potential noise changes and include them in economic assessments (e.g. ODA, 1998)

Greenhouse gas emissions and potential climate change impacts are more important issues. Some measures that reduce the emissions of SO_2, NO_x and PM_{10} lead to efficiency reductions and so increase CO_2 emissions: examples exist for both stationary and mobile pollution sources. The converse also follows. The current emphasis on reducing greenhouse gas emissions and possible mechanisms such as clean development mechanisms (see box below) may improve CO_2 emissions but do nothing for local air quality.

Potential conflicts between local and global pollution abatement

The Clean Development Mechanism (CDM) is one of several 'flexibility mechanisms' established by the 1997 Kyoto Protocol to the United Nations Framework Convention on Climate Change. The Protocol specifies legally binding limits on the emissions of greenhouse gases from most industrialised countries so that collectively, by the period 2008 to 2012, these emissions will be at least 5 % lower than in 1990. To help minimise the costs of achieving these targets, the CDM allows governments or companies in industrialised countries to invest in emission reduction projects in developing countries, where abatement can be cheaper, in order to meet their emission objectives. Projects that qualify under the CDM must lead to emissions reductions that are additional to those which would have happened anyway and should also contribute towards achieving sustainable development in the host countries. The CDM therefore has the potential to channel billions of pounds from industrialised to developing countries while offering them access to the latest 'clean' technologies and helping to promote a more environmentally sustainable path for their economies.

In the context of urban air pollution, however, there is a potential conflict with CDM in cases where measures that improve local air quality do so at the expense of CO_2 emissions – this is not uncommon for abatement technologies. Because of these reasons, ongoing DFID work (R7312 – Prioritising Opportunities Under the Clean Development Mechanism) is looking to screen potential CDM opportunities for such environmental effects, alongside technical and economic criteria, and social and development effects. The use of many of the tools in this guidance to assess potential local air quality could also be included when looking at possible options of schemes for CO_2 abatement in developing countries.

It is possible to include estimates of potential climate change damage in economic terms – examples were provided in Chapter 2 (with a current central estimate of $80/t$CO_2$). The incorporation of CO_2 effects in the economic analysis of local air quality measures would help avoid these potential conflicts and this is a recommendation for the guidance here – i.e. it would give preferential rank measures that were low-emission, low-carbon technologies.

Incorporation of carbon based assessments into local air quality management may lead to a re-examination of certain aspects of air quality management. It may mean that slightly more expensive options are given a higher priority, in recognition of their CO_2 benefits. However, this also opens up potential mechanisms for funding opportunities, which should allow investment for air quality improvements.

However, we highlight the issue of incorporating local air quality concerns into climate based policies as a priority –measures aimed at offsetting greenhouse gas emissions in developing countries may fail to take account of more important local environmental issues. Moreover, estimates that rank climate change amelioration measures in terms of costs per tonne of CO_2 abated alone, will not lead to measures which can most effectively improve local quality of life and environment.

This area is highlighted as one that warrants further research as a priority.

4.5 Social-Economic, Equity and Inequality Effects

In interpreting cost data or in assessing the costs of different measures it is important some consideration of other economic or socio-economic effects are taken into account. In essence, this means that the cost-benefit analysis described in previous sections should be supplemented by broader social and economic considerations – such as through stakeholder analysis or input.

To illustrate – the case study undertaken in China identified that in many urban areas there are some extremely old industrial plants, many of which are loss making, which have very high air pollution emissions. In many cases the costs of abatement for these plants are so high as to remove this as a realistic cost-effective option. Under such conditions, plant closure is extremely cost-effective, as it reduces very large emissions for little or no cost. However, any such action will have social and economic consequences for the local community (from loss of employment opportunities, from loss of local economic multiplier effects, etc). Consideration of these effects alongside other criteria is important – it does not mean that the plant should not be closed, but can help in making sure any local economic effects are mitigated through re-investment in the area.

As well as employment, there are a number of other potentially important effects that need to be considered. Many of these are associated with transport. The assessment of transport measures needs to consider other key appraisal criteria, notably accidents and congestion.

Any measures that seek to change or reduce traffic must take account of the potential effects on accidents (so that, for example, measures doe not affect local road safety levels). Similarly, the assessment of the potential effects of congestion (an important economic impact in it's own right) must be considered. To illustrate, previous studies on local transport measures have concluded that some transport schemes, such as road pricing or congestion charging reduce urban pollution and generate income. However, there are a number of issues that warrant consideration. Firstly, such schemes may lead to diverted traffic and generate greater congestion (and air pollution) along other roads. Secondly, in terms of the economic effectiveness, although the costs to the local implementing authority may be positive and generate revenue, they merely transfer additional financial cost to the local community and add costs to local businesses. Finally, there are potential inequality effects from such schemes, as they may lead to economic exclusion for poorer groups affecting accessibility and mobility.

The latter point (effectively social welfare or social justice) is extremely important. In many cases, the environmental benefits from air quality improvements will benefit the poor greatest (for the reasons outlined in Chapter 3). However, there is a danger that economic efficiency-based policies may benefit the rich more than the poor, and in some cases, may hurt the poor. Any assessment of potential measures should include an assessment of equity and inequality issues, the latter addressing whether options have potential social or economic benefits in relation to poorer or more vulnerable groups. Some initiatives may impact upon lower socio-economic groups to a greater extent than other sections of the community and these effects are not captured by purely economic considerations. There are some techniques that can be used to help assess potential social or social-economic effects, such as social impact assessment. These usually involve some form of stakeholder involvement to ensure social equity issues are considered.

The aim of such an approach is to ensure social equity, and to increase the transparency of the decision making process. By considering such aspects, air quality management should give higher priority to measures that have positive poverty alleviation aspects (and less priority to those that lead to inequality effects) all other things being equal. Indeed, it is worth considering whether poverty aspects should be given additional weighting, such that less cost-effective options are introduced in cases where they have significant poverty alleviation aspects.

Equity requires appropriate burden-sharing in the costs and benefits of environmental protection, with particular attention to the poor. For example, public transport funding can provide far more subsidy for wealthier rail users than for poorer, mostly minority bus users (Litman, 1999a). Similarly, there are cases in which lower income neighbourhoods are negatively impacted by transportation projects, while receiving little benefit, e.g. building commuter motorways through low-income suburbs. Subsidies may sometimes be appropriate, for poverty as well as environmental reasons, but they should be carefully designed to ensure that they are received by the intended beneficiaries (IIEC, 1997).

It should be stressed that assessing the short-term and long-term distributive impacts of options and projects, particularly on low-income groups, is difficult. For example, it is difficult to balance the economic consideration against the (immediate) human costs of poverty. Further research is warranted to identify ways of presenting these potential impacts. Potential options include displaying effects in a balance-sheet type of format, for consideration by decision-makers, as an adjunct to an options conventional cost-benefit assessment. Alternatively, different weightings could be attached to the cost benefit values representing the gains and losses affecting different social or income groups.

4.6 Measures and Options for Air Quality Improvements

The following sections provide a brief review of possible options or measures for air quality improvements by sector. In each case we have tried to include reference to the cost-effectiveness of measures, any potential other environmental effects especially greenhouse gas emissions, any other social or economic effects they have, and highlight specific equity or inequality effects (positive and negative) affecting poor or vulnerable groups.

When considering options for air quality improvements, common practice is to differentiate between stationary and mobile sources – because of the different emissions patterns from the two. For both, however, there is a broad spectrum of possible options that can be used to improve air quality. Summaries of the Strategies and Policies for Air Pollution Abatement in Europe (ECE, 2000) summarises possible measures as follows:

a) Measures related to Emission Control Technology
- Technology requirements in legislation and regulations
- Control technology requirements for stationary sources
- Control technology requirements for mobile sources

b) Regulatory Measures
- Air Quality Standards
- Target loads or deposition standards
- Fuel quality standards
- Emission standards and emission limit values
- Licensing of potentially polluting activities
- Product regulations
- Other regulatory measures

c) Economic Instruments
- Emission charges and taxes
- Product charges, taxes, and tax differentiation including fuel taxes
- Emission trading
- Subsidies and other forms of financial assistance
- Other economic measures

d) Other Measures
- Market incentives
- Voluntary agreements
- Management schemes

Some of the key options, by sector, are presented below.

4.6.1 Electricity, Industry and Commercial

Detailed data are available on the options for stationary sources for energy related combustion. In detailed studies, options are usually broken down by the following economic sectors:
- Electricity supply industry (ESI);
- Large industrial;

- Small industrial;
- Refineries;
- Iron & steel;
- Commercial.

In this study, we are only considering energy related emissions and for brevity have considered all sectors together. In any air quality management programme addressing an entire urban area, other process emissions will arise and differentiation between sectors and sub-sectors is more important.

Options for these sectors tend to focus on technology options, especially end of pipe abatement technologies and more energy efficient processes and technologies. Common options for abatement are described in the box below.

Technological Abatement of Combustion Emissions

The common pollutants from energy-use affecting urban air quality are sulphur dioxide, oxides of nitrogen, particulates and hydrocarbons. Abatement technologies common to processes are described below.

Abatement technologies for SO_2 include Flue Gas Desulphurisation. Four flue gas desulphurisation (FGD) processes are potentially available; limestone or lime slurry scrubbing; lime slurry scrubbing with spray drying; dry sorbent injection; and a hybrid process of dry sorbent injection process followed by a carbon reactivation stage (known commercially as LIFAC). Advanced technologies with Modified Combustion Processes. Two modified combustion process have been considered; integrated gasification combined cycle (IGCC) and pressurised fluidised bed combustion (PFBC). IGCC has been considered for electricity generation and large industrial sectors. PFBC is only applicable to solid fuels and is therefore applied to coal in all sectors other than refineries. The other major option is fuel switching. This can include moving to lower sulphur content fuels (for both solid and liquid fuels) and for both, switching to natural gas.

For NO_x there are two main types of abatement technology from combustion sources: combustion modifications and flue gas treatment. There are five types of combustion modification that are often used in combination: low excess air; over fire air; low NO_x burner; fuel staging; flue gas re-circulation. Flue gas treatments can be divided into dry and wet processes. Dry flue gas treatment for NO_x reduction involves selective catalytic reduction (SCR), selective non-catalytic reduction (SNCR), dry adsorption or wet processes. These methods can be and are used alone or in combination with combustion modifications.

There are four well-established **PM_{10} abatement technologies**, suitable for installation in combustion plant: mechanical collectors (cyclones); fabric filters; electrostatic precipitators; wet scrubbers. Efficiencies are variable; cyclones are typically about 90%, while fabric filters and electrostatic precipitators are about 99%, with some up to 99.8% (IEA 1996).

Considerable data are available on the costs of such technical abatement options, described in the box below.

Of course, pollution abatement is wider than ‘end of pipe techniques’. Many aid agencies including the World Bank, UN and the EC in its aid role, agree that avoiding pollution is more sustainable than funding ‘fix it’ projects. Many of the agencies nurture a ‘prevention is better than cure’ culture through the programmes they support that include the introduction of cleaner technologies the promotion of energy conservation and other policy measures to provide incentives to reduce the emissions of pollutants.

There are a large number of non-technical measures or policies that can be introduced, though these will vary according to the urban area under analysis. Examples include potential fiscal measures – for example energy in developing countries is often subsidised; in extreme cases the average price paid for electricity by consumers is less than the cost of making it. The usual argument for such subsidies is that they make electricity more affordable for poorer people and thus improve their lives; but first the new consumers need to be connected to the grid, and in developing countries that privilege is largely reserved for the urban middle classes. At the same time they put a heavy burden on public spending, and they encourage the profligate use of power. So reducing subsidies and raising prices, although politically difficult, can be a cheap and effective way of preventing waste.

However, less information on the effectiveness and costs of non-technical measures are available – a consequence of the fact that such options have not historically been used as widely, but also because of the location specificity for such options.

Cost-Data for Stationary Sources

There is considerable cost data for technical options. Sources of techniques for reducing air pollution from Industrial sources can be found at:

- United Nations Environment Programme, Industry and Environment Office http://www.unece.org
- European Integrated Pollution Prevention and Control Bureau http://eippcb.jrc.es
- United States Environmental Protection Agency http://www.epa.gov/oar/oaqps
- German Federal Environment Agency http://www.umweltbundesant.de

Details of costs for Europe have been compiled by IIASA (http://www.iiasa.ac.at/) in the RAINS model. The 'Regional Air Pollution Information and Simulation' (RAINS)-model has been developed as a tool for the integrated assessment of alternative strategies to reduce acid deposition in Europe and Asia. The Emission-Cost (EMCO) Module estimates costs for the reduction of emissions. Options and costs for controlling emissions of the various substances are represented in the model by considering the characteristic technical and economic features of the most important emission reduction options and technologies (Amann, Cofala, Klaassen, 1994). Regional and national potentials for emission control and the associated costs are estimated on the basis of detailed data on the most commonly used emission control technologies. The cost evaluation is based on international operating experience of pollution control equipment (e.g., Schaerer, 1993) by extrapolating it to the country-specific situation of application. A free and competitive market for the exchange of emission control technology is assumed. Important country-specific factors with strong impact on abatement costs are the characteristic sulphur content of fuels, plant capacity utilization regimes, boiler sizes etc.

CATC- The Clean Air Technology Center serves as a resource for all areas of emerging and existing air pollution prevention and control technologies, and provides public access to data and information on their use, effectiveness, and cost. CATC includes RACT/BACT/LAER Clearinghouse (RBLC). (http://www.epa.gov/ttn/catc/) The Clean Air Technology Center (CATC) serves as a resource on all areas of emerging and existing air pollution prevention and control technologies, and provides public access to data and information on their use, effectiveness and cost. In addition, the CATC will provide technical support, including access to EPA's knowledge base, to government agencies and others, as resources allow, related to the technical and economic feasibility, operation and maintenance of these technologies. CATC maintains a technology data base called the RACT/BACT/LAER Clearinghouse * or RBLC. The RBLC provides data on prevention and control technology determinations made primarily by state and local permitting agencies. The Clearinghouse contains over 3,500 determinations that can help you identify appropriate technologies to mitigate or treat most air pollutant emission streams. The RBLC was designed to help permit applicants and reviewers make pollution prevention and control technology decisions for stationary air pollution sources and includes data submitted by 50 states and territories in the U.S. on over 200 different air pollutants and 1,000 industrial processes.

The potential options for reducing urban energy-use emissions for stationary sources are summarised in the Table below. Most of the technical options centre on larger scale electricity or energy production processes. As well as the potential air quality benefits and cost-effectiveness, the Table includes discussion of other environmental or social-economic effects, acceptability and highlights any specific poverty related implications.

Table 7. Potential options for Reducing Energy-use Emissions – Electricity Generation and Industry.

Option	AQ benefit	Costs/Cost-effectiveness	Other environment, social-economic, equity and inequality aspects
Options directed at NO_x			
Low NO_x burners	20 – 50% reduction in NO_x	Low costs, high cost-effectiveness	
De NO_x selective catalytic reduction	80-90% reduction	high capital cost and significant operating costs	
Selective non-catalytic reduction	40 - 50% NO_x reduction	high capital cost and significant operating costs	
Options directed at SO_2			
Flue gas desulphurisation	Typically 90% in SO_2	High costs	CO_2 penalty and produces gypsu
Clean coal – fluidised bed	90-95% reduction in SO_2	High costs though usually higher efficiency plant	Gypsum generated as product of process.
Clean coal IGCC	Up to 98% reduction in SO_2	High costs though usually higher efficiency plant	
Low sulphur fuels	Variable	Usually cost-effective, though depend on transport costs	
Options directed at PM_{10}			
Coal washing			
Mechanical collectors (cyclones)	90%		
Fabric filters	Up to 99% reduction TSP		
Electrostatic filters	Up to 99.9% reduction TSP		CO_2 penalty
Web scrubbers	Up to 100%		
Other technical measures			
Fuel switching to gas	Relative to coal almost 100% reduction in PM_{10} and SO_2 and 50% in NO_x.	Depends on fuel prices. Maybe higher than coal.	Typically around a 50% reduction in CO_2.
Renewables	100% reduction in emissions	Typically high capital costs	Almost 100% reduction in CO_2.
Other measures			
Energy efficiency – housekeeping	10-15% improvements	Highly cost-effective (usually positive)	
Energy efficient technology		Highly cost-effective (usually positive)	
Process changes	Variable		
Plant restraint (e.g. constraining operation	Variable	Obvious cost	Social and economic consequences for local

times)			community, economy and industry.
Plant closure	Total emissions reductions	Obvious cost	Social and economic consequences for local community, economy and industry.
Development planning & control, e.g. siting plant away from residential areas	Can be high.	Variable	Will affect transport. Can impact on employment through selection of plant types and size.

4.6.2 Domestic Sector

The use of energy within the domestic sector is a key area for urban air quality improvements, especially with respect to the urban poor. Large problems exist in cases where poor quality coal or biomass is burnt directly in houses. Policies towards cleaner fuels or electrification can therefore have very large benefits, both in improving air quality but also in improving overall quality of life. Electrification potentially offers greater benefits, though there can be problems with social acceptability. For example, in the Republic of South Africa the sudden change from solid fuels to fully electric systems can counter important cultural aspects (people continue to use solid fuels for cooking even after electrification, because of the importance of the fire as a central gathering point for the family). In such cases, temporary measures, such as smokeless or cleaner fuels may provide an important stepping stone.

Urban and land-use planning can also have an important role in improving environmental impacts. Planning can be used to maximise benefits through provision of certain infrastructure (gas supply, CHP, solar power electricity, etc.).

The options are summarised in the Table below. Again, as well as the potential air quality benefits and cost-effectiveness, the Table includes discussion of other environmental or social-economic effects, acceptability and highlights any specific poverty related implications.

Table 8. Potential options for Reducing Energy-use Emissions – Domestic.

Option	AQ benefit	Costs/Cost-effectiveness	Other environment, social-economic, equity and inequality aspects
Smokeless fuel to replace poor quality coal (or biomass)	Reduction of low-smoke fuels relative to household coal. Very high reductions in particulates, and usually also in SO_2 and VOCs	May a cost penalty over conventional fuel, but in terms of emissions reductions/air quality improvements are very cost-effective	May be slight CO_2 penalty from additional manufacturing stage. Very high benefits for urban poor (as poor quality coal and biomass choice of fuel for urban poor).
Smokeless zones	As above	As above	Potential issues where cleaner fuel is more expensive.
More efficient stoves	Large energy efficiency improvements and reductions in all pollutants	Highly cost-effective	CO_2 benefits from improved energy efficiency.
Electrification	100%	Dependant on electricity price	CO_2 effects depend on generation mix. Very large benefits for improving air quality in poorer areas.
Domestic gas	Relative to coal almost	Dependant on fuel	Typically 50% reduction in

	100% benefits in PM_{10} and SO2. Up to 50% reduction in NO_x	price	CO_2.
Local renewables (for heating and lighting)	100%	Costs high	Almost 100% reduction in CO_2
Energy efficiency (lights, fridges, insulation, etc)	Large energy efficiency improvements	Very cost effective though high capital costs. Can depend also on whether subsidised electricity prices.	Large reductions in CO_2.

4.6.3 Transport

Both technical and non-technical measures exist for reducing emissions from transport. In contrast though the non-technical options are more numerous than for other sectors. The potential options are presented in the Table below. The focus here has been on aspects that are potentially important for developing countries, so we have not included some of the more advanced technology options.

Table 9. Potential options for Reducing Transport Emissions.

Option	AQ benefit	Costs/Cost-effectiveness	Other environment, social-economic, equity and inequality aspects
Technical solutions			
Unleaded petrol	100% lead reduction		Alternative to lead required. Refinery implications. Should benefit poor more because of exposure levels
Three-way catalysts	90% reduction in CO, NO_x and VOC	Extra cost per vehicle.	Slight greenhouse gas penalty.
Low SO_2 fuel especially diesel (city diesel)	Major SO_2 reductions, some PM_{10} reductions.		Refinery implications.
CNG vehicles	90-100% reduction in SO_2, PM_{10}, benzene over diesel, 50% reduction in NO_x	Investment and infrastructure costs	Quieter – noise benefit. For dedicated vehicles definite net greenhouse gas emissions benefits
LPG vehicles	CO is reduced by over 20%, THCs by >40% and NO_x by >30% (as compared to petrol).	Investment and infrastructure costs	Life-cycle greenhouse gas emissions benefits
Biofuels	Marginal local air quality benefits.		Very large CO_2 benefit.
Electric vehicles	100% (locally)	Very high	Quieter – noise benefit.
Urban traffic control systems	5-15% reduction in emissions from improved flow along roads applied	High costs to implement.	Improvement in traffic flow may lead to congestion benefits and reductions in noise
Non-technical			
Economic and fiscal measures (fuel taxes, vehicle taxes)			May impact upon lower socio-economic groups Potential issues of secondary noise or congestion from diverted traffic.
Emission exhaust legislation			Price of tightening standards passed onto consumer.

Emission monitoring programmes	Up to 50 % for NO_x emissions and 25% for PM_{10}.		May impact upon lower socio-economic groups.
Roadside checks (Inspection and maintenance)			May impact upon lower socio-economic groups. Acceptability
Public information, driver awareness	Fuel efficiency of 10-15% easily possible	Low – usually positive	Associated CO_2 benefits.
Parking controls along busy roads	1-10% reduction in emissions from improved flow along roads applied	Negligible	
Scrapage subsidies			

Option	**AQ benefit**	**Costs/Cost-effectiveness**	**Other environment, social-economic, equity and inequality aspects**
Speed limit controls – speed reductions along urban highways	5-10% reduction in emissions from improved flow along roads applied	Negligible	Improvement in traffic flow may lead to congestion benefits and reductions in noise
Road pricing in urban areas and highways	5-25% reduction in traffic depending on levels	Costs to build and operate offset by revenue.	Likely to impact upon lower socio-economic groups. Often leads to problems from diverted traffic.
Area bans (low emission, no-drive days zones, permit entry, licence plate bans)	Effectiveness varies.	Direct costs can be low.	May divert traffic elsewhere and lead to congestion. May impact upon lower socio-economic groups – exclude poorer people with older vehicles.
Parking restrictions in central areas			
Improved public transport		Can be high	Improved access and comfort. Reduction in social exclusion.
New transport systems (e.g. tram, light rail)	Lower emissions, plus can lead to modal shift	Tend to be very high	Noise consideration. Usually CO_2 benefits. Costs of new systems may exclude poor. Land-take issues - especially equitable and efficient resettlement.
Bus priority measures	5-30% benefits for buses.		May affect traffic flow for other vehicles and lead to no net benefits. May exacerbate congestion.
Improvement of cycling and walking			Provided separated from motorised transport, then large benefits. Physical activity benefits also.
Encouraging high occupancy vehicles			
Planning			
Land use/development planning	Variable	Reduction in low density urban sprawl and initiatives such as development corridors likely to lead to other benefits. May just divert traffic – lead to congestion and noise reductions in urban centre, but shift elsewhere. Moves local economic income. Helps avoids private car demand and social or economic exclusion.	
Pedestrianisation	100% in area of implementation.	May divert traffic. Potential effects on local business. Reduces potential for accidents and injury. Reduction in noise. Quality of life benefits on local amenity.	

Bypass/ring roads	High infrastructure and planning costs. Can potentially reduce traffic and congestion (though often only increase overall demand). Land-take issues for new development. Equitable and efficient resettlement for poorer groups. Divert noise and air pollution to different areas. Community severance.
low car dependency areas and car-free developments	Reduces potential for accidents and injury. Reduction in noise. Quality of life benefits on local amenity.

It is important to note that studies have shown that for many local measures, greater potential reductions can be achieved with combinations of measures, rather than implementing measures individually (for example combining measures to reduce traffic demand at the same time as encouraging or investing in public transport).

It is worth stressing that less cost data is available for transport on the costs of non-technical measures. The reason is the costs of these schemes are more difficult to assess – there are fewer examples available and they are usually extremely site specific. In addition, the actual effectiveness of many non-technical measures varies on a scheme by scheme basis. In many cases, this centres on how well local people respond to policies to move them from private cars to public transport. For example, measures to ease urban congestion, such as traffic management measures or fiscal incentives (e.g. road/congestion pricing) require investment in public transport if they are going to be effective. In order to stimulate behavioural change, it is key that viable alternatives are available.

In other cases, sustained enforcement appears to be key to limiting congestion and controlling air pollution. A number of south-east Asian cities have suffered reversals in tackling congestion primarily because incremental improvements in congestion led to disproportionate increases in the number of vehicles on the streets.

Finally, there are wider issues associated with transport that mean assessment of options must go beyond environmental effects. Transport has significant quality of life benefits through access to goods and services, economic and social development. However, it also has important inequality effects, including economic and social exclusion, which are felt most acutely by the poor. A diverse transportation system that provides a variety of travel choices suitable for different situations and needs tends to be more efficient and equitable. Having a variety of travel choices that can be used by lower income increases vertical equity, particularly increasing their employment opportunities. The experience in major developing cities indicates that this diversity, and particularly the quality of service and overall affordability of travel for non-drivers, can decline as the city becomes increasingly automobile-dependent due to lost economies of scale, reduced investment in alternative modes, a degradation in the pedestrian and cyclist environment, and increasingly auto-oriented land use patterns that are poorly suited for walking, cycling and transit access (see e.g., IIEC, 1997).

4.7 Other Useful Sources of Information

There are a number of International initiatives that have very relevant content to this study. A number of these are summarised below.

4.7.1 URBAIR

The Urban Air Quality Management Strategy Guidebook assists local institutions in developing action plans as an integral part of their air quality management system. Applied in different Asian cities, it gives a step-by-step guide for city-specific air quality reports. The guidebook provides details on air quality modelling, choices of abatement measures, and how cost-benefit analysis is used to choose appropriate measures. It summarises the components of an action plan to manage and control air pollution. A number of URBAIR city reports exist (e.g. Jakarta, URBAIR, 1996b) which provide valuable examples of the sorts of approaches recommended here.

4.7.2 Clear Air Initiative in Latin America

In terms of specific options and costs for developing countries, the World Bank has a Clean Air Initiative in Latin American cities (http://www.worldbank.org/wbi/cleanair/initiative/). The mission of the Clean Air Initiative is to improve air quality in Latin American cities by bringing together the efforts of leaders from the public and private sectors, the NGO community, research and academic institutions, government agencies, and international institutions. The work programme covers three components:

- City-specific action plans and workshops in Buenos Aires, Lima, Mexico City, and Rio de Janeiro;
- A Clean Air Web site and distance learning courses to share best practices on air quality management; and
- Public-private partnerships to encourage the use of low-pollution, low-carbon technologies

Clean Air Toolkits aim to give governments, industry representatives, local researchers, non-governmental organizations, international and local experts tools and relevant information to design and implement policies and strategies to prevent further emissions, restore air quality in Latin American urban areas and reduce further impacts to the global environment. Toolkits can be used as a reference, which includes step-by-step information for stakeholders involved in urban air quality management in Latin America or related policies and strategies. Planners and engineers may refer to the toolkits for technical assistance and to create an action plan to control air pollution.

The Toolkits provide lists of pollution abatement measures, cleaner technologies and Latin American experiences to improve air quality in cities. They may include air pollution reviews of regulations, policy instruments (e.g. command-and-control instruments, economic instruments and communication tools) that foster awareness, enhance participation of stakeholders and improve the effective implementation of pollution control measures and air quality management programs.

Implementing improved vehicle and fuel emission standards is a necessary step for achieving low emissions from the transport sector. This Toolkit provides professionals with information about current vehicle emission standards in some Latin American countries, namely: Argentina, Brazil, Chile, Colombia and Mexico. The main international standards and testing procedures adopted by Latin American countries are also presented. These include standards and regulations from the United States, California, the Economic Commission For Europe (ECE), and the European Union. Finally, relevant tax policies from Germany and Denmark are shown

4.8 Conclusions

This chapter reviews energy-related measures that can be used to improve air quality and how they can be prioritised.

Different options or measures for improving air quality have traditionally been evaluated in terms of their 'cost-effectiveness', i.e. the costs of implementing a measure and the likely air quality improvements it is likely to achieve (in cost per tonne or per unit of air quality improvement). This information is then used to help set air quality management, planning and strategy – measures can be ranked in order of cost-effectiveness as a means of prioritising. The air quality plan can then be implemented by selecting the most appropriate measure or combinations of measures to achieve the necessary air quality targets for least cost.

Well-established methods exist for assessing the costs of measures. However, this approach is usually aimed at specific pollutants and contrasts with the aim of air quality improvement to improve overall air quality for all pollutants. Moreover, many measures lead to reductions for a number of pollutants. Finally, air quality management should aim to reduce health and environmental impacts. It is therefore the environmental effects of emission sources that give rise to higher levels of exposure (e.g. low level sources) are taken in account. All of these issues can be addressed by using the recommended approach for assessing the environmental benefits (in reductions in physical impacts and economic damages) given in Chapter 2. This allows the evaluation of the net environmental benefits of measures (and ratio of benefits to costs) as a more appropriate means of ranking and prioritising measures.

The chapter also identifies a number of areas which are not typically included in the assessment of local air quality improvement measures, or indeed, in most air quality management plans. These include other environmental effects notably climate change, secondary economic effects of measures, and finally, equity and inequality issues. These other criteria are extremely important and we recommend they should be considered in producing a balanced air quality management programme.

Greenhouse gas emissions and potential climate change impacts are becoming increasingly important. There is, however, potential conflict between local air quality and global climate - some measures that reduce emissions of local air quality pollutants do so at the expense of increasing CO_2 emissions. Therefore, we recommend that estimates of the potential effects of climate change are included in the analysis of local air quality measures. This should give higher prioritisation to measures to improve local air quality that have low carbon emissions all else being equal. We also highlight the implications of this argument in assessing mitigation measures for carbon. Measures to address greenhouse gas emissions that also have a beneficial effect on local air quality should be given higher prioritisation. These local effects could be included in the economic assessment of GHG abatement through methods set out in this document. This area is highlighted as one that warrants further research as a priority.

Socio-economic and equity considerations are also extremely important. As well as assessing the costs and effectiveness of measures, broader social and economic considerations need to be taken into account. Potential congestion and employment effects are often considered in evaluation criteria. However, there is a growing recognition that maximising equity considerations and reducing inequalities are also important, for example, assessing whether options have potential social or economic impacts/benefits in relation to poorer or more vulnerable groups. By considering such aspects, air quality management can give higher priority to measures that alleviate poverty (and avoid those that lead to inequality effects). Indeed, it is worth considering whether equity consideration should be given additional weighting, such that less cost-effective options are introduced in cases where they have significant poverty alleviation aspects. It should be stressed that assessing the short-term and long-term distributive impacts of options and projects, particularly on low-income groups, is difficult. For example, it is difficult to balance the economic consideration against the (immediate) human costs of poverty. Further research is warranted to identify ways of presenting these potential impacts. Potential options include displaying effects in a balance-sheet type of format, for consideration by decision-makers, as an adjunct to an options conventional cost-benefit assessment. Alternatively, different weightings could be attached to the cost benefit values representing the gains and losses affecting different social or income groups. As a final note, the role of stakeholder analysis or input could provide an important part of helping to bring these aspects to the ranking and prioritisation exercise.

Finally, the chapter presents a review of possible measures for reducing the environmental effects of urban energy use. Within the assessment, the analysis has included reference to the cost-effectiveness of measures, any potential other environmental effects especially greenhouse gas emissions, their social or economic effects, and highlight any specific equity or inequality effects (positive and negative) affecting poor or vulnerable groups.

5 Conclusions

This report summarises the evidence relating to urban energy-related emissions and their environmental effects. It provides guidance on how to target resources by assessing the costs and benefits of different air quality improvement measures, whilst taking other important environmental, social-economic and equity considerations into account.

Energy related emissions arising from industry, transport and the domestic sectors are typically the dominant cause of poor air quality in urban areas. The emissions from the use of fossil fuels in all of the above sectors release a number of common pollutants affecting local and regional air concentrations. However, different sectors affect air quality differently due to the height and nature of the emissions they release, as well as the balance of different pollutants.

Urban air quality has a number of important environmental impacts. These include impacts on human health, buildings, and local amenity. Urban air quality can also impacts on crops, forests and natural ecosystems through regional pollution. The greenhouse gas emissions from energy-use also have global effects through the potential impacts of climate change.

Major advances over recent years now mean it is possible to quantify these health and environmental effects and the report provides guidance on the methodology to do this. The recommended approach follows a number of steps, namely:

- To quantify the emissions from the pollutant source;
- To assess the impact on air pollution concentrations in the surrounding area from these emissions (using air pollution dispersion models);
- To assess the population or receptors exposed to these pollution increases;
- To use exposure-response functions that link pollution to health or damage endpoints.

This step by step approach is known as a bottom-up or impact pathway approach. The approach takes account of the location of emissions and receptors. It can therefore differentiate between the relative effects of emissions on air quality from ground level releases, such as transport and high-level stack emissions.

There is an additional final step that can be undertaken using this approach: to convert the environmental effects into economic units. This allows the consideration of different effects on different receptors in equivalent terms. It also provides a means for incorporating environmental decisions alongside traditional economic criteria when considering, for example, how to prioritise different options.

These environmental costs are not included in the costs paid directly by energy users. For this reason, they are known as ‘external costs’ or ‘externalities’. There is a recognition that the monetary evaluation of environmental impacts needs to be incorporated in appraisal and decision support tools.

Valuing environmental damages in this way remains somewhat controversial. However, objectors ignore the simple fact that measures for improving the environment cost money. Monetisation provides a mechanism for comparing the benefits to be gained from alternative environmental improvement strategies, and hence a framework for deciding how best to spend the money that is available. It is also a reasonably transparent process, explicitly demonstrating the weights attached to effects considered. In the long-run, this should facilitate a more objective debate on pollution control than has hitherto been possible

The impact pathway approach with economic valuation of environmental effects has been widely used by the European Commission and countries such as the UK and the US in recent years. Applications include the use of the approach to provide policy makers with advice on issues such as air quality policy, and development of transport, waste and energy strategy.

The study has reviewed and produced guidance on quantifying and valuing health and non-health effects for ambient urban air quality, based on review of the literature. Health impacts are identified as the most important economic effect of poor air quality, with the pollutant PM_{10} as the major cause of concern. Uncertainties do exist in the use of the techniques recommended here, and to help communicate this, impacts have been given uncertainty rankings to allow any user to undertake sensitivity analysis. There is also an issue of transferability between Western studies and developing countries. This issue is relevant both for some of the health effects, notably the lack of information on the transferability of chronic health effects, and for the monetary valuation of all health effects.

The report also provides a very brief review of the economic costs of greenhouse gas emissions. Monetary values have been recommended for possible use in economic frameworks based on the central values that exist in the literature, though we stress that the valuation of climate change is more uncertain than other areas and recommend that associated values are presented separately to other impact categories.

It is stressed that most of the relationships and methods proposed in this report have been derived from studies in developed countries. This is not ideal, and it will inevitably lead to some bias, but is unavoidable given the relatively few studies undertaken in developing countries. The need for more research studies in developing countries, in order to bridge this gap, is highlighted as a priority area.

One area where this is particularly apparent is with the quantification of the health effects of indoor pollution. It is likely that there are major health effects from the use of solid fuels in the homes of urban areas. These health effects are likely to be additional to the effects from ambient air pollution identified in the guidance and these should be included (additionally) in the analysis of air pollution in urban areas. At present the best method to do this draws on the approach used for ambient air pollution, though this is not ideal. We highlight the identification of methods for quantifying indoor air pollution from domestic energy as a research priority from this review.

It is highlighted that the field of environmental economics is a rapidly advancing. All the underlying relationships and values recommended maybe subject to change and need to be kept updated on a regular basis. We also conclude that greater steps are needed to ensure consistent methods are used internationally for assessing these effects, as well as their associated uncertainties.

The study has also reviewed the literature concerning air quality impacts on poor and vulnerable groups. Of course, for people living in poverty the most pressing priority is the satisfaction of the basic human needs such as shelter, availability of potable water, sanitation, etc. However, the review shows that the poor tend to suffer from the effects of air pollution dis-proportionately, and that poor air quality itself actually exacerbates poverty.

These effects occur firstly because of location. Within most cities, the less affluent districts tend to be concentrated in areas with a higher density of roads, traffic and industry. Moreover, because the poor are less concerned with the impacts of air pollution and less well informed about its impacts, less controls over pollution or new plant are introduced in these areas. The effect is also seen between cities: areas at a higher level of economic development tend to have lower air pollution due greater levels of secondary and tertiary industries and higher efficiency and greater pollution controls on primary industry.

Secondly, air pollution problems are compounded for the poor as they typically use energy very inefficiently, with the use of low efficiency technology and poor quality fuel. Elevated ambient air concentrations are typically found in areas where solid fuels are used in the home for domestic heating. However, a much greater problem for these areas arises from indoor air pollution. These problems are often exacerbated by the lack of good ventilation systems. In cases where solid fuels are used extensively for domestic space heating (e.g. countries with colder winters), indoor air pollution is likely to dominate the health effects on the urban poor.

As well as being exposed to higher levels of air pollution, the poor are also more likely to be affected by air-polluted illness because of pre-disposing factors. Moreover, for these impacts, it is the elderly and children that are most at risk. Air polution can also impact on certain groups more because of exposure patterns. This can lead to higher air pollution exposure for specific social or economic groups. For example, within the family, the length of time spent in the highly polluted home will vary, with women, children and the elderly spending greater lengths of time in these conditions. Air pollution related illness also adds additional financial burden from medical care (if affordable) or a reduction in the ability to work (earning ability) from air pollution related illness.

Given these effects, we conclude that air pollution measures that aim to address energy use for the poor are likely to have very large benefits in improving air quality, and in turn reducing associated health and economic impacts. Thus, reducing the impact of urban energy use is a key aspect in the development process . However, it is necessary to target resources towards the most efficient ways of improving air quality.

The final area of the study therefore presents guidance on how energy-related measures can be assessed and prioritised.

Different options or measures for improving air quality have traditionally been evaluated in terms of their ‘cost-effectiveness’, i.e. the costs of implementing a measure and the likely air quality improvements it is likely to achieve (in cost per tonne or per unit of air quality improvement). This information is then used to help set air quality management, planning and strategy – measures can be ranked in order of cost-effectiveness as a means of prioritising. The air quality plan can then be implemented by selecting the most appropriate measure or combinations of measures to achieve the necessary air quality targets for least cost.

Well-established methods exist for assessing the costs of measures. However, this approach is usually aimed at specific pollutants and contrasts with the aim of air quality improvement to improve overall air quality for all pollutants. Moreover, many measures lead to reductions for a number of pollutants. Finally, air quality management should aim to reduce health and environmental impacts. It is therefore the environmental effects of emission sources that give rise to higher levels of exposure (e.g. low level sources) are taken in account. All of these issues can be addressed by using the recommended approach for assessing the environmental benefits (in reductions in physical impacts and economic damages) given in this guidance. This allows the evaluation of the net environmental benefits of measures (and ratio of benefits to costs) as a more appropriate means of ranking and prioritising measures.

The study has also identified a number of areas that are not typically included in the assessment of local air quality improvement measures, or indeed, in most air quality management plans, but which are important. These include other environmental effects notably climate change, secondary economic effects of measures, and finally, equity and inequality issues. We recommend they should be considered in producing a balanced air quality management programme.

Greenhouse gas emissions and potential climate change impacts are becoming increasingly important. There is, however, potential conflict between local air quality and global climate - some measures that reduce emissions of local air quality pollutants do so at the expense of increasing CO_2 emissions. Therefore, we recommend that estimates of the potential effects of climate change are included in the analysis of local air quality measures. This should give higher prioritisation to measures to improve local air quality that have low carbon emissions all else being equal. We also highlight the implications of this argument in assessing mitigation measures for carbon. Measures to address greenhouse gas emissions that also have a beneficial effect on local air quality should be given higher prioritisation. These local effects could be included in the economic assessment of GHG abatement through methods set out in this document. This area is highlighted as one that warrants further research as a priority.

Socio-economic and equity considerations are also extremely important. As well as assessing the costs and effectiveness of measures, broader social and economic considerations need to be taken into account. Potential congestion and employment effects are often considered in evaluation criteria. However, there is a growing recognition that maximising equity considerations and reducing inequalities are also important, for example, assessing whether options have potential social or economic impacts/benefits in relation to poorer or more vulnerable groups. By considering such aspects, air quality management can give higher priority to measures that alleviate poverty (and avoid those that lead to inequality effects). Indeed, it is worth considering whether equity consideration should be given additional weighting, such that less cost-effective options are introduced in cases where they have significant poverty alleviation aspects. It should be stressed that assessing the short-term and long-term distributive impacts of options and projects, particularly on low-income groups, is difficult. For example, it is difficult to balance the economic consideration against the (immediate) human costs of poverty. Further research is warranted to identify ways of presenting these potential impacts. Potential options include displaying effects in a balance-sheet type of format, for consideration by decision-makers, as an adjunct to an options conventional cost-benefit assessment. Alternatively, different weightings could be attached to the cost benefit values representing the gains and losses affecting different social or income groups. As a final note, the role of stakeholder analysis or input could provide an important part of helping to bring these aspects to the ranking and prioritisation exercise.

The document presents a review of possible measures for reducing the environmental effects of urban energy use. Within the assessment, the analysis has included reference to the cost-effectiveness of measures, any potential other environmental effects especially greenhouse gas emissions, their social or economic effects, and highlight any specific equity or inequality effects (positive and negative) affecting poor or vulnerable groups.

Finally, the work has undertaken two case studies to assess the practicality of the guidance and to investigate issues of data availability and local issues. The two case studies have been undertaken in China and in the Republic of South Africa (RSA).

The China case study demonstrates the use of the guidance for assessing the environmental impacts and economic effects of air pollution. The results show just how important these potential effects are. In the city of Shenyang where the case study was based, ambient air pollution may lead to 5,500 deaths per year, along with a similar number of serious health episodes and many million minor respiratory illnesses. Sensitivity analysis on possible chronic effects shows that air pollution might lead to up to a million years of life lost in the population each year, though there is a much higher uncertainty associated with this number. In economic terms, these potential effects are extremely important and our estimates of the health effects (quantifying only the most certain of impacts) leads to an annual damage cost of $370 million/year. The study has also evaluated the potential costs of measures to improve air quality and conclude that most air quality amelioration measures have net economic benefits.

The case study in the RSA set out to undertake a similar analysis, though problems with data availability have meant that this is not possible (an important conclusion in itself). However, the study has provided important information on the issues associated with indoor air quality from domestic heating. This case study has also considered the potential effects of options for improving air quality in more depth to illustrate potential areas of interest. Particular attention has been paid to the assessment of associated climate change effects and on whether certain measures have particular benefits to the urban poor. Interestingly the study has identified some potential conflicts – measures that target the domestic sector have been identified as the key area with positive aspects for poorer groups. However, a number of the most cost-effective short-term measures have CO_2 penalties (for example the use of smokeless fuel to replace domestic coal burning). In such cases, options are available that can lead to local air quality and greenhouse gas emissions benefits (electrification or domestic gas), though these tend to be more expensive and may have to overcome strong cultural barriers for successful introduction. These studies highlight the potential difficulties in balancing these different criteria.

A number of areas have highlighted as research priorities. These include:

- Research into the health effects of indoor air pollution. The existing literature is driven by the assessment of ambient air pollution. This study identifies indoor air quality from domestic energy use as a major source of health impacts, especially for the urban poor, and the key area that warrants further investigation.
- International co-operation and co-ordination to help agree the methods described here, to agree protocols for dealing with uncertainty, and to tackle the issues of transferring economic values (and also a number of impacts such as the chronic health effects) from developed to developing countries. This includes further in-country studies to grow and adapt the guidance presented here, which inevitably has a Western bias.
- Potential synergies and conflicts between local air quality improvements and greenhouse gas emissions. In the course of this work, we have come across examples where conflicts exist between these two areas. The incorporation of climate change concerns in air quality management is highlighted as a key conclusion of this guidance, as is the need to further develop the sorts of methods here to help prioritise carbon mitigation options.
- The incorporation of equity issues with existing frameworks for assessing options. The guidance here has only managed to identify that these issues are potentially very

important: further work is needed to transfer these findings through to actual frameworks that can allow consideration of traditional criteria alongside these issues.

Taken together, it is hoped that the guidance here can help in drive the selection, implementation and prioritisation of measures which achieve most environmental benefits (by targeting most important pollutants and sources) and which are appropriate, cost-effective, equitable and locally and globally sustainable.

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