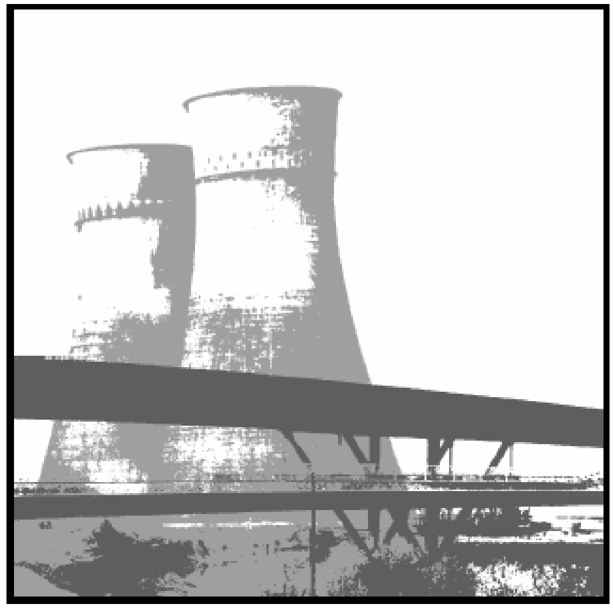

Air Pollution and Noise
their effects on human health and social inclusion
a review of recent literature

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Air Pollution and Noise: their effects on human health and social inclusion - a review of recent literature

Executive Summary

This review of recent papers looks at the growing body of evidence of how environmental factors, and particularly road-traffic related air pollution, affect health. Some of the most recent studies focus on the effects of small particulates which penetrate to the lungs and their adverse effects on cardiovascular disease, coronary heart disease, and stroke. Other studies have highlighted the disproportionate burden of environmental degradation, particularly air quality and noise, on deprived communities, with consequent impacts on increasing social deprivation.

Impacts of air pollution on health

Pollutant	Effects related to short-term exposure	Effects related to long-term exposure
Particulate matter	• Lung inflammatory reactions • Respiratory symptoms • Adverse effects on the cardiovascular system • Increase in medication usage • Increase in hospital admissions • Increase in mortality	• Increase in lower respiratory symptoms • Reduction in lung function in children • Increase in chronic obstructive pulmonary disease • Reduction in lung function in adults • Reduction in life expectancy, owing mainly to cardiopulmonary mortality and probably to lung cancer
Ozone	• Adverse effects on pulmonary function • Lung inflammatory reactions • Adverse effects on respiratory symptoms • Increase in medication usage • Increase in hospital admissions • Increase in mortality	• Reduction in lung function development
Nitrogen dioxide (in ambient air, NO_2 serves as an indicator for a complex mixture of mainly traffic-related air pollution)	• Effects on pulmonary function, particularly in asthmatics • Increase in airway allergic inflammatory reactions • Increase in hospital admissions • Increase in mortality	• Reduction in lung function • Increased probability of respiratory symptoms

Source: World Health Organization, 2004, p7

Children (and the unborn foetus) are especially vulnerable to the effects of air pollution, because their lungs, metabolic and immune systems are still developing, they have higher rates of respiratory infections, and have activity patterns which lead to higher exposure. The effects in childhood and foetal development can include:

- aggravation of asthma
- increased cough and bronchitis
- low birth weight
- infant deaths (due to respiratory and Sudden Infant Death Syndrome)
- pre-term births
- birth defects

leading to effects throughout adult life:

- premature ageing
- higher risk of infection
- susceptibility to tobacco smoke
- susceptibility to occupational exposure.

Air pollution has been associated with a range of health impacts, including:

- aggravating and causing respiratory disease (including asthma, bronchitis, emphysema, etc.)
- increased risk of cardiovascular disease and death
- increased risk of coronary heart disease and death
- increased risk of stroke
- eye disease
- DNA damage.

Many studies have tried to assess both how much air pollution contributes to ill health, and how much that ill health costs.

Quantifiable human health impacts of air pollution

Effect
Chronic effects on: Mortality Adults over 30 years Infants Morbidity Bronchitis Acute effects on: Morbidity Respiratory hospital admissions Cardiac hospital admissions Consultations with primary care Physicians Restricted activity days Use of respiratory medication Symptom days
Acute effects on: Mortality Morbidity Respiratory hospital admissions Minor restricted activity days Use of respiratory medication Symptom days

Source: Holland et al, 2005, p3.

Examples of the costs of air pollution from Europe, the UK and Sheffield

European Union	• kills 370,000 people per year • reduces life expectancy by up to 9 months on average • costs between €427 billion and €790 billion per year
United Kingdom	• 6,500 deaths brought forward (in 2002) • 6,400 hospital admissions (in 2002) • A 1 $\mu g/m^3$ decrease in $PM_{2.5}$ would give between 1.5 and 3.5 extra days of life per person • NOx damage per tonne emission for 2010 €3,900 (low estimate) • $PM_{2.5}$ damage per tonne emission for 2010 €37,000 (low estimate) • SO_2 damage per tonne emission for 2010 €6,600 (low estimate)
Sheffield	• 6% coronary heart disease deaths • 11% stroke deaths • Annual health costs of £48.1m (low estimate) based on: – 8,000 tonnes per annum NOx emissions (£20.9m) – 1,480 tonnes per annum SO_2 emissions (£6.5m) – 1,190 tonnes per annum PM_{10} emissions (£20.7m - costs estimated on $PM_{2.5}$ being 70% of PM_{10}) • Estimated annual cost benefits of introducing a Low Emission Zone between £1.8 million and £11.4 million per year (compared with inner relief road, costing £59m capital costs, bringing annual cost benefits of £0.03m to £0.2m)

Noise and health

As well as the adverse effects of air pollution on health, road traffic generates noise which affects health in the following ways:

- annoyance
- sleep disturbance
- quality of sleep
- ischaemic heart disease
- impaired performance by school children
- some evidence to suggest that it may cause low birthweight in babies and psychiatric disorders.

Conclusion

The growing body of evidence would suggest that bolder and more effective measures should be taken to reduce people's exposure to air pollution and noise attributable to road-traffic and thus reduce their risk of disease and mortality due to cardiovascular, respiratory, and other symptoms. The evidence suggests that there is no safe level of exposure to particulate matter, and especially to very small particles ($PM_{2.5}$) which penetrate into the lungs. Many studies highlight the possible under-estimates of the health effects of traffic-related air pollution and noise, due to problems in isolating these from other effects on health.

The most deprived communities experience the worst environmental degradation. The implications for policy therefore would seem to be to target measures to reduce air pollution in deprived areas and highly populated urban areas, where the relatively small individual health benefits can make a big impact because they reach a large population. Concerns about the U.K.'s ability to meet current targets to reduce air pollution, particularly in urban areas, further emphasise the need for reducing motor vehicle traffic but at the same time enhancing alternatives such as walking, cycling, and public transport.

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Introduction

During 2005, more studies have added to the growing body of evidence which shows how environmental factors affect health. This report mainly reviews recent papers on the health effects of road-traffic related air pollution. Some of the most recent studies (published during 2005) focus on the effects of small particulates which penetrate to the lungs and their adverse effects on cardiovascular disease, coronary heart disease, and stroke. Some studies have highlighted the heavier burden of environmental degradation, particularly air quality and noise, on deprived communities with consequent impacts on increasing social deprivation. Air pollution has been associated with a range of health impacts, including increased risk of cardiovascular disease, respiratory disease (including asthma and bronchitis), eye disease and DNA damage.

Many studies have shown the disproportionate burden of environmentally attributable disease which falls on children: *"Up to 40% of the global burden of disease attributable to environmental factors is estimated to fall on children under the age of five years"* (EEA/WHO, 2002). Roberts (2003) said that children from families without a car (generally from more deprived neighbourhoods) were more likely to suffer higher pedestrian death rates than children from car-owning families, because they walk more. There is growing recognition about the danger of air pollution to the unborn child, with several studies published during 2005 looking at its links with low birthweight, pre-term birth, retarded foetal growth, birth defects, and neo-natal deaths. Currently, many studies show either inconclusive or inconsistent results, but further research is on-going.

Studies on asthma and other respiratory symptoms have often focused on younger people. Throughout the world, studies have found traffic-related air pollution to be associated with increased mortality, both in children and adults, which increased with proximity to major roads. Studies published during 2005 have highlighted increasing recognition of links with cardiovascular problems.

The debate continues about how to assess the contribution to outdoor air pollution made by road-traffic, how to measure people's exposure to it, and how to assess the effects of individual and combined pollutants on health and, once quantified, how to express those impacts in financial terms.

Of particular interest to local people, a number of recent case studies have used Sheffield as an example. These include two recent studies into hospital admissions and deaths due to coronary heart disease, and stroke deaths (Maheswaran et al, 2005a & 2005b). A Defra report (Watkiss et al, 2004b) compares cost benefits for a range of measures (including low emission zones, improved public transport schemes, etc) to reduce traffic congestion and improve air quality.

The ability of policies, such as the introduction of Air Quality Management Areas, to improve health, has been questioned. Mitigation measures were sometimes seen as ineffective, or watered-down due to their perceived unpopularity among voters and industry. Concerns have been raised about whether the U.K will have achieved its goal of air quality targets by the end of 2005, and lower targets by 2010 to improve health.

The final section of this report briefly summarises the health impacts of noise. Road-traffic noise has been associated with impaired concentration amongst schoolchildren and lower achievement levels, raised blood pressure and lower psychological well-being.

This revised edition includes an executive summary and glossary of useful terms and abbreviations.

Environmental equity and social inclusion

Wheeler and Ben-Shlomo (2005) compared data from the Health Survey for England with a small area index of air pollution (using annual mean concentrations of the most common pollutants). Their study added to previous studies (below) of environmental inequity in the UK. They found *"urban lower social class households were more likely to be located in areas of poor air quality … and the adverse effects of air pollution seem to be greater in men in lower social classes"*.

Walker et al's report (2003) for the Environment Agency underlines *"the general recognition that deprived communities are likely to experience disproportionate levels of pollution and other forms of environmental degradation"*, with empirical evidence. They examined the distribution of *"environmental bads (such as pollution) and goods (such as access to greenspace)"* within society. They found:

- Integration Pollution Control (IPC) sites were disproportionately clustered together in deprived wards.
- In England, the most deprived wards were clearly associated with the highest pollutants for air quality, with *"people in deprived wards … exposed to concentrations higher by 41% than those of wards of average deprivation".*

Jerrett et al (2001) found property value to be the most significant predictor of exposure to pollutants, as *"people with lower incomes or with unstable incomes over time are unlikely to purchase homes that they cannot pay for over the long term."* Low income and unemployment were also significantly associated with greater exposure to air pollution.

Launching his department's contribution to the Government's Neighbourhood Renewal Strategy in December 2001 Environment Minister, Michael Meacher, said:

> *"We can boost health and well-being by improving local air quality and tackling fuel poverty. Improving the environment in which people live and work is every bit as important as tackling economic and social challenges, and can make a real difference to people's lives."*

The government, mindful of this, made improving air quality in deprived areas an important neighbourhood renewal target (National Deprivation-related Targets 2002 PSA6). Pye et al's report (2001) for Defra concluded:

> *"For the English cities (London, Birmingham studied), policies to reduce NO_2 and PM_{10} could have greater benefits for more deprived communities based on the results from this analysis, and for central urban locations that have highest concentrations of these pollutants".*

Walker et al (2003) found that, in England, the most deprived wards were those with the highest pollutant concentrations, and that people in deprived wards were exposed to NO_2 concentrations 41% higher than those of wards of average deprivation. Their study found that *"the number of people resident in wards above high pollution thresholds increases progressively with increasing deprivation"* and that *"of the 10% of the population resident in wards with poorest air quality, we* *typically find that half reside in wards that are amongst the 20% most deprived in the country."*

Brunekreef and Holgate (2002) suggested that the effects on life expectancy of exposure to particulate matter could be greater for more disadvantaged groups, whilst Jerrett et al (2001) described this as a *"triple jeopardy"* in that disadvantaged groups suffered:

- increased risk from social and behavioural determinants of health
- air quality worse in deprived neighbourhoods
- effect modification that makes exposure to pollution exert disproportionately large health effect compared with advantaged groups.

Air quality and health

Table 1: Impact of air pollution on health

Pollutant	Effects related to short-term exposure	Effects related to long-term exposure
Particulate matter	• Lung inflammatory reactions • Respiratory symptoms • Adverse effects on the cardiovascular system • Increase in medication usage • Increase in hospital admissions • Increase in mortality	• Increase in lower respiratory symptoms • Reduction in lung function in children • Increase in chronic obstructive pulmonary disease • Reduction in lung function in adults • Reduction in life expectancy, owing mainly to cardiopulmonary mortality and probably to lung cancer
Ozone	• Adverse effects on pulmonary function • Lung inflammatory reactions • Adverse effects on respiratory symptoms • Increase in medication usage • Increase in hospital admissions • Increase in mortality	• Reduction in lung function development
Nitrogen dioxide (in ambient air, NO_2 serves as an indicator for a complex mixture of mainly traffic-related air pollution)	• Effects on pulmonary function, particularly in asthmatics • Increase in airway allergic inflammatory reactions • Increase in hospital admissions • Increase in mortality	• Reduction in lung function • Increased probability of respiratory symptoms

Source: World Health Organization, 2004, p7

The World Health Study (2004), from which Table 1 above is taken, summarises recent information on the effects of air pollution on health. The review indicates that current levels of air pollution in Europe impose a considerable health burden. Adverse health effects linked to air pollution include increased risk of cardiopulmonary disease, and reduced life expectancy of a year or more.

Yamazaki et al (2005) sampled the Japanese general population to compare exposure to NOx and PM, where they found a lower "vitality" score for groups exposed to higher concentrations of NOx. Lai et al (2005) found, in a small study in Taiwan, that exposure to traffic exhaust increased oxidative DNA damage.

Carlisle and Sharp (2001) studied the effects of exercise and air pollution in the UK, and recommended that people should avoid traffic, particularly during rush hour when NOx, CO, and VOCs would be high; that outdoor exercise should be avoided during cold smoggy weather; that running or cycling should be done either early morning or late evening on hot bright days; that CO levels inside pubs and cars could have detrimental effects on athletic performance.

Effects of air pollution on children's health and during pregnancy

A joint report by the European Environment Agency and the World Health Organization (EEA/WHO, 2002) gives an overview of the health hazards suffered by children due to transport, particularly in modern urban environments, where they spend a considerable amount of time being driven in a car. They cite a study conducted in Amsterdam in 1990 which compared in-vehicle concentrations of CO with exposure of cyclists travelling the same routes, whose exposure was always lower than the vehicle occupants. An earlier WHO study indicated children living near busy roads had a 50% increased risk of suffering from respiratory diseases. Children are at higher risk than adults of road accidents, having limited perception of and reaction to road traffic dangers. Parents react to the fear of traffic accidents by restricting their children's freedom to walk and cycle, thus contributing to unhealthy levels of inactivity, and increasing levels of obesity and weight problems, bringing increased risk of cardiovascular disease, diabetes and hypertension in adulthood.

As part of the WHO's systematic review of health aspects of air pollution in Europe, WHO (2005b) and Binková et al (2004) suggested that children are especially vulnerable to exposure to air pollution than adults:

> *"The ongoing process of lung growth and development, incomplete metabolic systems, immature host defences, high rates of infection by respiratory pathogens and activity patterns specific to children can lead to higher exposure to air pollution and higher doses of pollutants reaching the lungs"* (WHO, 2005b, p3).

Developing lungs exposed to air pollution in childhood reduces maximum functional capacity, leading to enhanced susceptibility in adulthood to the effects of ageing and infection, tobacco smoke and occupational exposure. The WHO studies found there was sufficient evidence to infer a causal relationship between exposure to air pollutants and

- adverse effects on lung function development
- aggravation of asthma (mainly due to exposure to particulate matter and ozone)
- increased prevalence of cough and bronchitis (due to particulate exposure).

The WHO studies found much of the childhood morbidity and mortality related to air pollution occurred via interactions with respiratory infections, to which children are more susceptible. They recommended more research into enhanced allergic sensitisation to children genetically at risk, and the links between outdoor air pollution and childhood cancer. The evidence reviewed indicated that reduced childhood exposure to air pollution could have significant health benefits in terms of decreased hospital admissions for respiratory complaints, lower prevalence of bronchitis and respiratory infections, and improved lung function and growth. Whilst the benefits to the individual child would be small, the widespread nature of exposure and high incidence of the relevant outcomes mean that *"the amount of ill-health attributable to air pollution among European children is high"* and they *"strongly recommended that children's current exposure to air pollutants be reduced, particularly in regard to traffic-related pollutants"* (WHO, 2005b, p5-6).

The WHO (2005b) and Binková et al (2004) studies found there was now sufficient evidence to infer a causal relationship between particulate air pollution and post-neonatal respiratory deaths. The evidence suggests a link between low birth weight and air pollution, but further study was suggested into this, and into links between air pollution, pre-term births and retarded foetal growth. The evidence was strongest for a link between particulates and infant deaths, but further research into exposure to specific pollutants and the timing of exposure was recommended.

Ponce et al (2005) studied the effects of traffic-related air pollution on pre-term births in Los Angeles county, California by studying birth records from 1994-1996, traffic counts, census data, and air pollution measures. They found traffic-related air pollution exposure disproportionately affected lower socio-economic neighbourhoods, with increased susceptibility during the winter amongst women with known risk factors.

Gilboa et al (2005) examined the relation between air quality and birth defects in Texas between 1997-2000. They compared maternal exposure to air pollutants duing weeks 3-8 of pregnancy with selected cardiac birth defects and oral clefts in live births, and foetal deaths. The results supported previous findings of some links, particularly with ozone exposure and pulmonary artery and valve defects, although the link with oral clefts was limited.

As studies in Asia, Europe and the Americas had provided inconsistent evidence that air pollution may affect birth weight, Mannes et al (2005) conducted a study in Sydney, Australia, between 1998-2000. Although air pollution levels in Sydney were quite low, they found a relationship between exposure to CO and NO_2 in the second and third trimesters of pregnancy had a significantly adverse effect on birth weight, and particulate matter had a small statistically significant adverse effect. They recommended further studies were needed.

Valent et al's review of published studies and reports (2004) found that between 1.8% and 6.4% of deaths from all causes in children aged 0-4 years were attributable to outdoor air pollution.

Research by Kaiser et al (2004) in the United States suggested that outdoor air pollution (above a reference level of 12.0 $\mu g/m^3$ PM_{10}) substantially contributes to postneonatal infant mortality (deaths after the first 4 weeks of life), particularly in relation to SIDS (Sudden Infant Death Syndrome) and respiratory disease in infants born with a normal birth weight. They reviewed other research, which suggested air pollution and, in particular vehicle exhaust, has an effect on foetal development, and thus affected respiratory and cardiovascular health in childhood and later life.

Gauderman et al (2004) looked at whether exposure to air pollution adversely affects the growth of lungs during a period of rapid development in children aged 10-18 years. They studied 1,759 children with an average age of 10 from 12 communities in south California and measured their lung function over 8 years. They found that lung development was impaired (by measuring the forced expiratory volume in one second, or FEV_1, and other measures) where children had been exposed to NO_2, acid vapour, $PM_{2.5}$ and elemental carbon. For example, 7.9% of 18-year olds exposed to the highest levels of $PM_{2.5}$ observed had a low FEV_1, compared with only 1.6% of those exposed to the lowest levels.

Yu et al (2004) monitored the lung function of 821 schoolchildren in Hong Kong whilst their parents completed medical diaries. These findings were compared with whether the children lived in high or low pollution areas. Physical exercise was associated with greater lung function in children from low pollution areas. Children from high pollution areas had lower lung function, even those who undertook regular physical exercise, suggesting that exercise in a polluted environment may not be beneficial for lung function.

Conceicao et al (2001) evaluated the association between child mortality and air pollution in Sao Paulo, Brazil, 1994-1997. They estimated approximately 15%, 13% and 7% of child respiratory deaths were associated with CO, SO_2 and PM_{10} respectively.

Asthma and respiratory symptoms

Chapter 3 of the EEA/WHO (2002) study examined asthma, allergies and respiratory health. It found the prevalence of wheezing in children aged 13-14 years in the UK to be 32.2%, the highest of the 21 countries included in the ISAAC study, 1995-96, and that the most consistent relationships between outdoor air pollution and respiratory health have been found for particulate matter and ozone.

Binková et al's review (2004) found sufficient evidence to assume a causal relationship between air pollution exposure (especially particulates and ozone) and aggravation of asthma, and a causal link between particulate exposure and cough and bronchitis.

Zmirou et al (2004) reported on the Vesta case-control study conducted in 5 French metropolitan areas, 1998-2000. 217 pairs of matched 4-14 year-olds were investigated by constructing an index of lifelong exposure to traffic exhausts. The results suggested that traffic related pollutants may have contributed to the "asthma epidemic" amongst children during the last few decades, although Devenny et al's study (2004) of 3,537 schoolchildren in Aberdeen, found that the prevalence of asthma and wheeze symptoms seemed to have stabilised, rather than to still be rising.

Migliaretti and Cavallo (2004) investigated the relationship between air pollution and emergency hospital admission for asthma among children in Turin (Italy), 1997-1999. They found a significant association between increased numbers of hospital emergency admissions for respiratory causes and exposure to NO_2 and particulates.

Peacock et al (2003) found no clear effects of any pollutant (NO_2 , SO_2, PM_{10} and ozone) on peak expiratory flow rate (PEFR) in their study of 179 children aged 7-13 from 3 schools in southern England, 1996-1997, although the effects of PM_{10} were stronger in wheezy children.

Brilhante and Tambellini (2002) compared emergency hospital admissions for respiratory diseases in 1991 with data of suspended particulate matter collected at Rio de Janeiro's Environmental Agency. The results showed that emergency admissions were more frequent in winter, and atmospheric pollution was higher in winter.

3,535 children with no history of asthma were recruited from schools in 12 communities in southern California and were followed for up to 5 years (McConnell et al, 2002). In communities with high ozone concentrations, the relative risk of developing asthma in children playing 3 or more sports was 3.3 compared with children playing no sports. Sports had no effect in areas of low ozone concentration. The study concluded that air pollution (ozone) and outdoor exercise could not only exacerbate previously undiagnosed asthma, but also be an increased risk for new-onset asthma in children with no previous history of wheezing.

Venn et al (2001) found that the effect of road traffic pollution on asthma was likely to be most marked among those who lived within 150 m of a main road. 6,147 primary school children aged 4-11 and 3,709 secondary school children aged 11-16 in Nottingham were tested in 1995-96. They found the risk of wheeze increased with proximity to the main road, particularly living within 90 m of a main road. Among primary school children, effects were stronger in girls than boys. A further article by Venn et al (2005) investigated the effects of living close to road traffic in Ethiopia, where road traffic is generally low and restricted to a limited network of roads. They found that those living within 150m of a road had an increased risk of wheeze than those living further away. This risk was slightly stronger for roads which carried more traffic.

The Chartered Society of Physiotherapy issued a media release (2005), calling on car manufacturers to reduce emissions of PM_{10} from diesel engines, in order to reduce the incidence of wheezing and shortness of breath, and premature death for sufferers of asthma and emphysema. They published measurements of PM_{10} from 61 monitoring sites in the UK. Readings from the site in the centre of Sheffield (29th out of the 61 sites) showed the annual mean ($\mu g/m^3$) had increased from 22 in 2004 to 23 in the first 6 months of 2005.

Burr et al's study (2004) using repeat questionnaires with 165 and 283 adults in an area which was subject to less heavy road traffic after the construction of a by-pass found that chest symptoms showed a greater improvement in the previously congested area, and particularly alleviated rhinitis and rhinoconjunctivitis.

Cardiovascular disease, coronary heart disease and stroke

COMEAP's report (2005) into the association between cardiovascular disease and air pollution concluded that both short and long-term exposure to fine particles ($PM_{2.5}$) sulphate particles and sulphur dioxide are associated with a reduction in life expectancy due to cardiovascular disease, and increased hospital admissions. The evidence pointed to a causal relationship between pollutants and cardiovascular disease, with consequent implications for public health. They recommended a precautionary approach be adopted in planning and policy development, and will shortly revise their quantification of the effects of air pollution in the UK. They proposed further research into the possible relationship between short-term fluctuations in people with Coronary Artery Disease (CAD), adverse coronary events, sudden death, and arrhythmia, and the incidence and time-lag of levels of air pollution.

Hinwood et al (2006) investigated the relationship between daily concentrations of $PM_{2.5}$, NO_2 and CO and hospital admissions from 1992-1998 in Perth, Western Australia. They found a small number of significant associations between all 3 pollutants and respiratory diseases, COPD, pneumonia, asthma and CVD hospital admissions.

Wellenius et al's study (2005) of Medicare patients in the Pittsburgh area of Pennsylvania during 1987-1999 found associations between levels of PM_{10} , CO, NO_2 and SO_2 and admission to hospital for congestive heart failure. Patients with a recent myocardial infarction were at greater risk of admission. Their study suggested that short-term increases in traffic-related air pollution may trigger acute cardiac episodes.

Gilmour et al (2005) tested the hypothesis that exposure to PM_{10} would result in inflammation and activation of coagulation mechanisms in pulmonary and vascular cells in the laboratory. They found that PM_{10} had the ability to alter cell function to favour blood coagulation.

Rich et al (2005) found an association between episodes of air pollution (ozone) in Boston, Massachusetts, and ventricular arrhythmias, between 1995-2002. People with a prior recent arrhythmia were more at risk.

Two recent studies published by a team from the University of Sheffield (Maheswaran et al, 2005a and 2005b) analysed stroke deaths and hospital admissions for coronary heart disease, 1994-1998, for people aged 45 and over based on census enumeration districts in Sheffield. They compared this data with modelled air pollution data for PM_{10}, NOx and CO, and took into account age, sex, socioeconomic deprivation and smoking prevalence. They found an excess risk of coronary heart disease mortality in areas with high levels of outdoor NOx (a proxy for traffic-related pollution), with approximately 6% of coronary heart disease deaths in Sheffield attributable to outdoor NOx (Maheswaran et al, 2005a). They similarly reported an excess risk of stroke deaths and hospital admissions in those areas, with approximately 11% of stroke deaths in Sheffield attributable to outdoor air pollution (Maheswaran et al, 2005b).

Mortality

The EEA/WHO (2002) review cited 3 studies (Bobak and Leon 1999, Loomis et al 1999, and Saldiva et al 1994) which found that air pollution was related to increased mortality from respiratory diseases in children, in the Czech Republic, Mexico City and Sao Paolo.

Miller's report (2003) for the Institute of Occupational Medicine assesses the impact of long-term exposure to air pollution and cardiovascular risk for population groups in the UK stratified to reflect differences in individual frailty or susceptibility. Previous studies had suggested that risks from air pollution were higher for cardiovascular than for respiratory causes. They predicted gains from a 1% reduction in all-cause hazards of 4.8 million life-years in England and Wales. They based their calculations on the population alive at the start of 2005. Their overall findings are summarised in table 6 below.

Table 2: Summary of life years gained (millions) across total population of England and Wales, estimated from different sets of assumptions and different impacts on mortality

Assumption	Mortality cause affected		
	All causes	Cardio-respiratory	Cardio-vascular
No stratification	4.784	4.415	3.39
Stratified population[A]	4.897	4.197	2.905
Sensitivity variable by strata[B]	4.595	4.618	3.829

Source: Miller, 2003, p15

Notes: A - Predictions calculated for 3 separate strata (susceptible, increased risk and normal) within each age and sex-specific subgroup.

B - Predictions calculated using the same strata as in A, but with the additional stratification of hazard factors (lung cancer, other cancer, cardiovascular, respiratory, accidents, and other).

Miller's report (above) built on a previous report for the Institute of Occupational Medicine by Miller and Armstrong (2001), which quantified the impacts of air pollution on chronic cause-specific mortality. They developed spreadsheet methods to calculate changes in mortality patterns for all-cause, cardio-pulmonary and cardio-vascular deaths.

Walter and FitzRoy (2000) examined air pollution and mortality in 13 British cities (including Sheffield) from 1992 to 1997. They looked at a range of pollutants: PM_{10}, SO_2, NO_2, CO, and ozone. They estimated that between 12,700 and 19,500 *"annual deaths in British cities are caused by air pollution, mainly from motor vehicles",* and *"the poor health of those individuals who ultimately succumb to pollution-induced conditions is likely [due to] the life-history of pollution".*

Maheswaran and Elliott (2003) calculated exposure to road traffic air pollution based on 113,465 enumeration districts in the 1991 Census of England and Wales. They found stroke mortality was 7% higher in men living within 200m of a main road compared with men living 1000m or more away. The corresponding increase for women was 4%, with the risk for men and women combined at 5%, and would account for approximately 990 stroke deaths per year. These raised risks diminished with increasing distance from main roads. Hong et al's study (2002) in Seoul, Korea, similarly found that air pollutants were significantly associated with ischaemic stroke deaths.

Roosli et al (2005) estimated years of life lost in Switzerland during 2000, using a dynamic exposure-response model for adult and infant deaths and air pollution emission data. They calculated a total of 42,400 years of life lost, with 4% of those being infant deaths.

Samet et al (2000) examined air pollution and mortality in 20 U.S. cities from 1987-1994. Similar to the Walter and FitzRoy study (above) they looked at PM_{10}, SO_2, NO_2, CO, and ozone, but trying to isolate the effects of PM_{10} from the other pollutants. They found *"consistent evidence that the levels of fine particulate matter in the air are associated with the risk of death from all causes and from cardiovascular and respiratory illnesses"*. A further study of 151 US metropolitan areas in the 1980s (Pope et al, 1995) found particulate air pollution was associated with cardiopulmonary and lung cancer mortality.

Zeka et al (2005) examined mortality data from the National Center for Health Statistics in 20 US cities, 1989-2000, compared with daily concentrations of PM_{10}. They found that all-cause mortality increased with higher levels of PM_{10} occurring either 1 or 2 days before. Deaths from heart disease were more associated with an increase in pollution 2 days before, whereas respiratory deaths were associated with exposure on the day itself, as well as 1 and 2 days before.

Hoek et al (2002) assessed the relationship between traffic-related air pollution and mortality in the Netherlands, using a random sample of 5,000 people aged 55-69 from 1986-1994. Long-term exposure to traffic-related pollution (black smoke and nitrogen dioxide) was estimated from the 1986 home address. They found a relative risk of 1.95 of cardiopulmonary mortality was associated with living near a major road, and a relative risk of 1.41 for total deaths, thus suggesting that long-term exposure to traffic-related air pollution may shorten life expectancy.

Filleul et al's analysis of the French PAARC survey (2005) found that urban air pollution assessed in the 1970s was associated with increased mortality caused by lung cancer and cardiopulmonary causes over 25 years in France. 14,284 adults from 7 French cities had enrolled in the PAARC survey of air pollution and chronic respiratory disease in 1974, and daily measurements of SO_2, total suspended particles, black smoke, NO_2, and nitric oxide were made for 3 years. The results were controlled for smoking, educational level, body mass index, occupational exposure and frailty.

Finkelstein et al (2004) estimated increased mortality rates in relation to air pollution. They tested lung function at a clinic in Ontario, Canada, between 1985 and 1999, and modelled mortality from all natural causes during 1992-2001 in relation to lung function, body mass index, diagnosis of chronic pulmonary disease, chronic ischaemic heart disease, diabetes, household income, and residence within 50m of a major urban road, or within 100m of a highway. They found that mortality rate was advanced by 2.5 years with residence near a major road, and advancement periods attributable to chronic pulmonary disease, chronic ischaemic heart disease, and diabetes were 3.4 years, 3.1 years and 4.4 years respectively.

Rainham et al (2005) studied weather patterns and their association with air pollution and human mortality in Toronto, Canada, 1981-1999. They found mortality reached a maximum in winter and a minimum in summer, although average air pollution concentrations were similar in both seasons.

A critical review of 2 air pollution studies was published on www.livingknowledgeconsulting.com in 2005, in relation to their implications for public health. 1 study was based in the US, the other in London. Both studies demonstrated the relationship between air pollution exposure (long and short term) and increases in deaths. Although air pollution has a relatively small effect, it is in important public health concern because of the large populations exposed. Recommendations included further research into susceptible groups, the effects of early life exposure, and the level at which air pollution might have a negligible effect on health, and transport policies to encourage the use of public transport and discourage private car use.

Quantifying and costing health impacts of exposure to air pollution

Many of the studies listed in this report detail the problems of assessing and quantifying people's exposure to air pollution. Various approaches have been used to link health statistics with air quality data. However, there are problems of consistency and availability of reliable data. For example, better recognition of disease over time may lead to changes in diagnosis; monitoring of air pollution has only become more widespread in recent years. This section illustrates some of the ways that have been used to estimate how much of an impact air pollution has on health. Many studies use a surrogate (NOx or PM) to represent total air pollution, but omit possible confounding effects when multiple pollutants are present. Most studies recognise that their estimates are conservative. Some studies have gone further, in giving a monetary value to the quantified impacts, with the consequent debate about how to cost more qualitative issues, such as life years lost or restricted activity days.

Table 3: Quantifiable human health impacts of air pollution

Burden	Effect
Human exposure to $PM_{2.5}$	Chronic effects on: Mortality Adults over 30 years Infants Morbidity Bronchitis Acute effects on: Morbidity Respiratory hospital admissions Cardiac hospital admissions Consultations with primary care Physicians Restricted activity days Use of respiratory medication Symptom days
Human exposure to ozone	Acute effects on: Mortality Morbidity Respiratory hospital admissions Minor restricted activity days Use of respiratory medication Symptom days

Source: Holland et al, 2005, p3.

Künzli et al (2000) and Brunekreef and Holgate (2002) used measures of nitrogen dioxide as a surrogate for other pollutants, particularly particulates PM_{10} and $PM_{2.5}$. Harrison et al (2002) compared daytime exposures by directly monitoring 11 healthy adults and 18 people from more susceptible groups (6 schoolchildren, 6 older people, and 6 with pre-existing cardiac or respiratory disease). Heinrich et al (2005) compared self-reported exposure to traffic-related air pollutants with GIS modelled and actual measured air pollution. They found that people felt they were exposed to higher levels of air pollution than modelled estimates predicted.

Roosli et al (2003) compared different approaches to quantifying cancer risk due to air pollution, comparing adding together the individual risks of single pollutants with using PM_{10} as a surrogate for total air pollution. They found that applying epidemiology-based risk methods using PM_{10} exposure resulted in a considerably higher risk of lung cancer than using the sum of unit risk based effects of single pollutants.

Schwela et al, eds (2002) reviewed the health effects of particle matter on health, and methods of assessing exposure. The studies they reviewed had consistently found an association between mortality (all causes, cardiovascular and respiratory) and particulate matter. A study by Diaz-Sanchez et al, 1997, raised concerns about diesel exhaust as a contributor to increased prevalence of asthma and allergic rhinitis.

DSS Management Consultants (2000) developed a software programme for the Ontario Medical Association to estimate the health and economic costs of air pollution. They analysed the impacts of ozone and particulates on human health, looking at premature mortality, hospital admissions, emergency visits, doctors' surgery visits and minor illnesses. They calculated economic damage by giving values to loss of life, quality of life, health care costs and lost productivity. They forecast that 1,900 premature deaths, 9,800 hospital admissions, 13,000 emergency visits and 46 million illnesses would result in the year 2000 due to air pollution, costing about $10 billion. These illnesses and deaths would increase over the next 20 years if air quality conditions remained constant, due to an expanding population, and the ageing of that population making it at higher risk.

Larssen et al (1999) estimated annual health impacts and costs related to PM_{10} pollution in 4 Asian cities, 1990-1993, as illustrated in table 4 below.

Table 4: Monetary value (in million US$) of annual health impact in 4 URBAIR cities for selected health indicators

Health impact	**Mumbai 1991**	**Metro Manila 1992**	**Jakarta 1990**	**Kathmandu Valley 1993**
Mortality	22.7	18.8	49.7	0.57
Mobidity				
Restricted Activity Days	17.2	67.7	69.4	0.53
Asthma attacks	24.3	19.8	6.9	0.23
Respiratory Symptom Days	39.0	59.1	1.6	1.51

Source: Larssen et al, 1999, p102

Tsai et al (2003) found an association between exposure to air pollution and hospital admissions for stroke, in their study of 23,179 admissions from 1997-2000 in Kaohsiung, Taiwan. On warm days there were significant positive associations between levels of PM_{10}, NO_2, SO_2, CO and O_3 and both primary intracerebral haemorrhage and ischaemic stroke admissions, but on cool days, only CO levels and ischaemic stroke admissions were significantly associated.

Researchers in Pennsylvania (Liao et al, 2004) randomly monitored heart beats in the population-based Atherosclerosis Risk in Communities Study, and compared their findings with air pollution levels. They found heart rate was adversely associated with higher levels of air pollution, and was more strongly associated with levels of PM_{10}, particularly in people with histories of hypertension and coronary heart disease. They suggested that the effects of exposure to air pollution on heart rate could be a potential mechanism through which air pollution is associated with cardiovascular disease.

Welty and Zeger (2005) looked at the National Morbidity, Mortality and Air Pollution Database in the United States using 2 different approaches to control for fluctuations in weather and season, and found that the estimated health risks from pollution were unaffected when controlling for weather.

Quantified and costed effects of air pollution on health in Europe

The CAFÉ study (Holland et al, 2005) costs the estimated health impacts of exposure to air pollution for the 25 European Union countries. The values given (in Table 5 below) are based on extensive studies (http://café-cba.org/ and http://europa.eu.int.comm/environment/air/café/activities/cba.htm). A news item in the BMJ (Watson, 2005) quotes the European Commission's estimate that air pollution kills 370,000 people in Europe every year, reduces average life expectancy by up to 9 months, and costs the EU economy between €427bn and €790bn a year.

Table 5: Summary of health valuation data for the CAFÉ study in the EU

Mortality	**Based on median values**		**Based on mean values**
Infant mortality	€1,500,000/death		€4,000,000/death
Value of a statistical life	€980,000/death		€2,000,000/death
Value of a life year	€52,000/year		€120,000/year
Morbidity	**Low**	**Central**	**High**
Chronic bronchitis	€120,000/case	€190,000/case	€250,000/case
Respiratory, cardiac hospital admission		€2,000/admission	
Consultations with primary care physicians		€53/consultation	
Restricted activity day		€130/day	
Restricted activity day (adjusted)		€83/day	
Minor restricted activity day		€38/day	
Use of respiratory medication		€1/day	
Symptom days		€38/day	

Source: Hurley et al, 2005, pvii.

The World Health Organization's fact sheet (WHO 2005a) looks at how particulate matter in air pollution harms health, both PM_{10} which can reach the upper part of the airways and lungs, and the more dangerous $PM_{2.5}$ which can penetrate deep into the lung and reach the alveolar region. PM_{10} normally remain in the atmosphere a few hours whereas $PM_{2.5}$ may remain for days or weeks and consequently be spread over longer distances.

Table 6: Estimated change in health damage due to PM in the EU through implementation of current legislation, 2000-2010

Health end-point	**Units (1000s)**	**2000**	**2020**	**Difference**
Mortality - long-term exposure	Life years lost	3,001	1,900	1,101
Mortality - long-term exposure	No. premature deaths	288	208	80
Infant mortality	Cases	0.6	0.3	0.3
Chronic bronchitis	Cases	136	98	37
Respiratory hospital admissions	Cases	51	33	19
Cardiac hospital admissions	Cases	32	20	12
Restricted activity	Days	288,292	170,956	117,336
Respiratory medication use, children	Days	3,510	1,549	1,961
Respiratory medication use, adults	Days	22,990	16,055	6,935
Lower respiratory symptoms, children	Days	160,349	68,819	91,529
Lower respiratory symptoms, adults with chronic disease	Days	236,498	159,723	76,773

Source: Pye S, Watkiss P, CAFÉ CBA: baseline analysis 2000 to 2020 www.iiasa.ac.at/docs/HOTP/Mar05/café-cba-baseline-results.pdf

Künzli et al (2000) reported on the World Health Organization study on the health impacts of long- and short-term air pollution in Austria, France and Switzerland. They estimated that 6% of all deaths were attributable to air pollution (about twice as many as were caused by road traffic accidents). They also examined the impact of air pollution on respiratory and cardiovascular hospital admissions, cases of adult chronic bronchitis, episodes of childhood bronchitis, restricted activity days for adults, and asthma attacks in children and adults. They quantified the economic costs of these health impacts and found that health costs equivalent to 1.7% of GDP were attributable to air pollution from traffic. Jerrett et al (2001) quantified the monetary costs of illness and death associated with particulate air pollution at about Can$537 million per year, using a programme developed for the Ontario Medical Association (DSS Management Consultants, 2000). Künzli et al's study concluded that the cumulative impact of air pollution upon not only length, but also on quality of life, is substantial:

> *" the project emphasises the need to consider air pollution and traffic-related air pollution as a widespread cause of impaired health."*

Brunekreef et al (1996) were among the first to attempt to quantify the health costs attributable to transport in Switzerland. Their findings are illustrated in table 7 below.

Table 7: External health costs due to traffic-related air pollution in 1993 in Switzerland (values in millions of Swiss Francs)

Effect of traffic-related air pollution based on PM_{10}			**Costs**
Loss of production	2,100	premature deaths per year	1,109
	10	disability cases per year due to chronic bronchitis	9
	12,100	hospitalisation days per year	3
	426,000	days off work per year	49
Immaterial costs	2,100	premature deaths per year	443
	10	disability cases per year due to chronic bronchitis	1
	800	hospitalisations per year	5
In-patient treatment costs	12,100	hospitalisation days per year	7
Out-patient treatment costs	31,000	cases of acute bronchitis per year	2
	22,000	cases of chronic bronchitis	10
	1.4	million days with asthma attacks per year	1
	8.0	million days with respiratory symptoms per year	< 1
	2,072	out-patient deaths per year	< 1
Administrative insurance costs		additional medical treatment	1
		reduction in transfer payments	- 8
Total health costs due to traffic-related air pollution			**1,632**

Source: Brunekreef et al, 1996, pS-10

In 1998, the World Health Organization carried out a health impact assessment study for the 8 largest cities in Italy (Turin, Milan, Bologna, Genoa, Florence, Rome, Naples and Palermo) using PM_{10} as a surrogate measure for other pollutants (WHO, 2001?). The population in 1991 was 8.3 million. Yearly average PM_{10} concentrations ranged between 44.4 and 53.8 $\mu g/m^3$. Dose response co-efficients for exposure to PM_{10} were derived from published literature and applied to population data in respect of mortality, hospital admissions (for CVD and respiratory disease), acute bronchitis, asthma exacerbation, restricted activity days, and occurrence of respiratory symptoms. The analysis was based on conservative assumptions of cases attributable to overall air pollution. They found that 4.7% of mortality was attributable to PM_{10} concentrations higher than 30 $\mu g/m^3$, with the same proportion for combined hospital admissions. Tens of thousands of attributable cases of childhood bronchitis and asthma exacerbation cases were estimated, as well as millions of days of restricted activity and episodes of respiratory symptoms. As the main source of PM_{10} in Italian cities was motor vehicle traffic (particularly diesels and two-stroke motorcycles), they suggested that curbing the volume of traffic in urban areas was warranted, especially as this would have other beneficial health effects (reducing road accidents, noise and community severance) and make walking and cycling (beneficial to health) more attractive alternatives.

Brunekreef and Holgate (2002) reviewed the evidence for adverse effects on health of selected air pollutants (ozone, particulates and nitrogen dioxide). Studies from the Netherlands, Austria, France and Switzerland suggested that about half of all deaths attributable to air pollution in general were due specifically to pollution from traffic

(20,000 deaths from a combined population of 74.5 million). The health effects examined by the studies they reviewed included respiratory and cardiovascular hospital admissions, bronchitis episodes, and restricted activity days, all of which produced similarly high numbers.

A study of 691 heart attack victims conducted in southern Germany from 1999-2001 (Peters et al, 2004) found that those exposed to traffic were nearly 4 times at risk of heart attack within an hour of exposure. The time their subjects spent in cars, on public transport, on motorcycles or bicycles was consistently linked with an increased risk of heart attack, with the use of a car being the most common source of exposure to traffic.

Research which investigated the short term association between the number of ophthalmological emergencies, urban air pollution, and climatic conditions in Paris (Bourcier et al, 2003) indicated a strong relation between NO (largely due to vehicle emissions) and NO_2 concentrations and conjunctivitis. NO, NO_2 and SO_2 also alter the lacrimal pH by acidifying tears and thus irritate the surface of the eye.

Quantified and costed effects of air pollution on health in the UK

King et al (undated) aimed to identify the origin of PM in air pollution from a number of UK locations. Their study found that comparisons of rural and urban PM_{10} measurements did not support the weight given to the significance of local traffic as a source of PM_{10} and recommended further research to better understand the source of UK urban PM.

Defra's Air Quality Expert Group (2005) suggest that particulates cause the most serious health problems to susceptible groups (people with pre-existing lung or heart disease, the elderly and children). As well as the health effects of long-term exposure (respiratory and cardiovascular illness and death), short-term exposure to PM_{10} in 2002 *"led to 6,500 deaths and 6.400 hospital admissions being brought forward that year"* (p5). They highlighted the COMEAP report of 2001 which indicated that each 1 $\mu g\ m^{-3}$ decrease in $PM_{2.5}$ could result in between 0.2 and 0.5 million years of life gained for the current population of England and Wales, or an average of 1.5-3.5 days for every individual. However, they highlight the fact that this effect would not be spread evenly throughout the population, and some people would gain much more. In 2003, there were 240 sites in the UK measuring PM_{10} and 123 sites monitoring black smoke, whilst modelling estimates are used in other areas. The report recommends *"a more flexible and holistic approach*" to the control of pollutants, due to the complexity of sources (road traffic and other regional contributors, and atmospheric effects), and their broader effects (acid deposits and climate change as well as human health).

Defra undertook a survey (Chilton et al, 2004) to determine willingness to pay (WTP) values for adverse health impacts of air pollution, such as chronic and acute mortality, emergency hospital admissions, and days of breathing discomfort. They found that WTP increased with

- the number of months of extra life expectancy in normal health
- per capita income or ability to pay
- number of people in the household, and
- increased perception that at least some members of the household would benefit.

Their findings resulted in the following values:

- £138,150m for 5m extra person-years of life in normal health
- WTP value of preventing a respiratory hospital admission of £1,310 - £7,110
- WTP value to avoid a day of breathing discomfort of £7 - £30 per day.

Table 8: Cost of total damage for NOx, $PM_{2.5}$ and SO_2 per tonne emission for 2010 in the UK

Pollutant	VOLY - median	VSL - median	VOLY - mean	VSL - mean
NOx	€3,900	€6,000	€6,700	€10,000
$PM_{2.5}$	€37,000	€57,000	€73,000	€110,000
SO_2	€6,600	€10,000	€13,000	€19,000

Source: Holland et al, 2005, pp15-17.

Based on the lowest estimate of pollutant costs from table 8 above, the annual health costs for Sheffield £48.1 million) can be calculated, as shown in table 9 below.

Table 9: Annual health costs for Sheffield

Pollutant	Emissions in Sheffield (tonnes per annum)	Annual health costs
NOx	8,000	£20.9m
PM_{10} [A]	1,190	£20.7m
SO_2	1,480	£6.5m
Total		**£48.1m**

Note A: Emissions data for PM_{10} is available for Sheffield, rather than for $PM_{2.5}$, and $PM_{2.5}$ is estimated to be 70% of PM_{10}.

Policy measures to combat air pollution and enhance health

The growing recognition that air pollution damages human health has led to policy measures being introduced to try to combat the trend. Kjellstrom et al (2003) proposed the integration of health impact assessment (HIA) and comparative risk assessment (CRA) into a framework for policy-makers and planners, to ensure comprehensive assessments are undertaken of decisions that affect complex health issues. They cite transport policy as particularly relevant. European legislation increasing restricts vehicle emissions and local councils in the UK are required to develop plans to lower air pollution in Air Quality Management Areas. These have included a range of proposals, such as low emission zones, traffic charging schemes, improved public transport, and intelligent transport systems to manage demand on congested roads. The European Commission was reported in the *BMJ* (Watson, 2005) as looking to regulate people's exposure to fine air-borne particles which penetrate deep into the lungs, and ozone pollution, by introducing new standards on car emissions, setting limits on allowable concentrations of smog in European cities, and updating existing legislation to make it more effective. Reductions of pollutants were originally set at 80% over the next 15 years, but were reduced to 75% for fine dust and 60% for ozone due to protests from industry.

Roberts (2003) welcomed the arrival of congestion charging in London as a welcome change from the government's *"tinkering around the edges of the problem"*. He compared it with the ineffective introduction of school travel plans in 2 inner London boroughs, where travel co-ordinators had successfully produced travel plans, but *"there was no evidence that these changed travel patterns or reduced parental fears"*. He concluded that, if congestion charging *"reduces deaths* *and injuries of pedestrians and cyclists, encourages walking, and reduces car use, then it will be a major public health reform, and Ken Livingstone will be to the walking classes what Edwin Chadwick was to the working classes."* As Ogilvie et al (2004) pointed out, *"Driving cars contributes to traffic congestion, air pollution, and the risk of injury and death to road users, whereas walking and cycling pose little risk to others and provide opportunities for physical activity".*

Watkiss et al's evaluation of the local road transport measures in relation to air quality strategy for Defra (2004b) highlights the limitations of focusing solely on achieving the air quality objectives, as they will not necessarily deliver maximum health benefits. They point out that reducing PM_{10}, particularly in urban areas, will achieve the greatest health benefits per tonne of pollution abated, due to high population densities. They looked at a number of measures, such as road user charging, light rail systems, bus lanes, guided busways, parking controls, roadside emissions testing, area access controls and vehicle scrappage subsidies. They also used a number of specific schemes in the UK to illustrate costs and benefits, one of which was the Sheffield northern inner relief route. They then applied the costs and effects of all the various measures to the Sheffield case study, as illustrated in table 9 below. These figures show that schemes which target air pollution (low emission zones, speed restrictions and vehicle scrappage) have the highest benefit to cost ratios, even over a modest lifetime of 10 years. On the other hand, local transport measures to reduce congestion, improve traffic flow, or enhance public transport have low cost benefit ratios in terms of solely air quality benefits, but this study did not take account of other benefits such as travel time, accidents, journey reliability, accessibility, etc.)

Table 10: Total capital costs (original scheme) and annual air quality benefits applied to the Sheffield case study for local transport measures

Scheme	**Total costs (£ million)**		**Annual Benefit (£ million)**	
	Ex Ante	**Ex Post**	**Central low**	**Central high**
LEZ (Euro2 + RPC)	not known		1.8	11.4
LEZ (Euro3)	not known		1.1	7.3
Speed restriction M1	0.7 to 4.8 capital only		0.4	2.5
Scrappage scheme (high)	8 to 20 total capital		0.4	2.4
Scrappage scheme (low)	4 to 10 total capital		0.2	1.2
Relief road	59 capital only		0.03	0.2
Oxford transport scheme	not known	4.8 capital only	0.02	0.1
CCS high	not known		0.01	0.09
Bradford quality bus initiative	not known	11.1 capital only	0.01	0.05
CCS low	not known		<0.01	0.04
Leeds quality bus initiative	not known	16.9 capital only	<0.01	0.01
Tram scheme low effect	not known	~200 capital only	<0.02	<0.1

Source: Watkiss et al, 2004, p54

Watkiss et al (2004a) evaluated the air quality strategy for Defra relating to both road transport and electricity policies. They highlighted the main health benefits for road transport policies arose from reductions in PM_{10}, and they illustrated the most successful policies in the past had been the introduction of unleaded petrol, low sulphur levels and Euro1 emission standards. They felt that targeted local transport policies could be more cost-effective than national policies in the case of NO_2, and measures to reduce PM_{10} should be targeted on large urban areas to achieve maximum health benefits.

There has been a consensus for some time that regular physical exercise makes a vital contribution to health (reducing cardiovascular disease, reducing the risk of developing diabetes, reducing blood pressure, and improving functional capacity) and well-being (improving social networks, reducing community severance) (Dora, 1999; Carnall, 2000; Roberts, 2003). However *"we now walk an average of eight miles less each day than our forebears 50 years ago"* (Carnall, 2000).

Jacobsen (2003) examined the relationship between the numbers of people walking and cycling, and the risk of road-traffic accidents. The results were surprising, in that the more people walked and cycled, the less likely it was that a motorist would be in collision with them. He concluded that policies which increased the numbers of people walking and cycling would be an effective way of improving the safety of pedestrians and cyclists.

Egan et al (2003) reviewed studies of the impact of new roads on health. They found that out-of-town bypasses reduced injuries on roads in and around towns, and reduced disturbance (including noise, vibration, fumes and dirt) and community severance in towns, but increased them elsewhere. New major urban roads had an insignificant impact on injuries, and increased disturbance and community severance (still significant 30 years after the road's construction, in 1 UK study).

Ogilvie et al (2004) reviewed 22 studies to assess what interventions were effective in promoting a modal shift from car use to walking and cycling. They found that targeted programmes could change the behaviour of motivated population subgroups, and access to a new rail station in Voorhout (Netherlands) gave a 5% shift. Publicity campaigns, engineering measures (extending cycle networks, slowing urban traffic, etc) and other interventions (car share, financial incentives, etc) had little effect.

Noise and health

As well as the adverse effects of air pollution on health, road traffic generates noise which affects health in the following ways: annoyance, sleep disturbance and quality, ischaemic heart disease, and impaired performance by school children. They found some evidence to suggest that it may cause low birthweight in babies and psychiatric disorders (The Medical Research Council, 1997). A very brief review of the evidence is summarised below.

The UK Noise Association (2001) found that 20% of people were badly affected by noise in the European Union. They found that the UK's towns had become 10 times noisier in the last decade (based on acoustic noise measurements in Sheffield since 1991), and that 66% of outdoor noise came from motor traffic. Socially excluded communities were hardest hit by traffic and aircraft noise, and poorer people could not afford to move away. The report recommended ways to cut traffic noise: quieter road surfaces, lower speeds, traffic calming, traffic reduction, and quieter vehicles.

Shield and Dockerell surveyed over 2,000 children aged 7 and 10 in London to find out how disruptive noise was. Internal and external noise surveys in schools, and experimental testing of children in different noise conditions was combined with a comparison of the results of Standard Assessment Tests (SATs). Teachers were also questioned about their perception of noise. The study found that most external noise came from road traffic; both external and internal noise levels were associated with lower SATs results; children were aware of and annoyed by external noise; children's judgements of noise levels were borne out by the researchers' measurements; classroom noise levels were often dominated by the noise the children made themselves; acute exposure to noise affected performance on academic tasks, particularly language-based tasks; children with special educational needs were particularly vulnerable to the effects of background noise. The researchers concluded that attention should be paid to appropriate acoustic design in schools to reduce noise levels.

Two papers published the findings of a study in Austria (Evans et al, 2001, and Lercher et al, 2002). They studied 2 cross-sectional samples of 1,280 and 123 primary school children aged 8-11. Children from the noisier areas had higher blood pressure when not under stress, elevated heart rate during reading tests, and rated themselves as having higher stress levels. Girls (but not boys) showed lower motivation levels.

Joynt and Kang studied the recently constructed motorway (M1) noise barrier in Tinsley in relation to local people's perceptions of the design process and the effectiveness of the noise barrier. The researchers found that, despite the local community having a well organised public forum, those involved in the design and management of the project failed to engage with local people. Feelings were mixed about whether the barrier had been successful in reducing noise; some felt the tree planting (by the local community Tinsley Tree Project) had been more effective.

Conclusion

The growing body of evidence would suggest that bolder and more effective measures should be taken to reduce people's exposure to air pollution and noise attributable to road-traffic and thus reduce their risk of disease and mortality due to cardiovascular, respiratory, and other symptoms. The health dangers for children and the unborn child, although not yet conclusive, would indicate that exposure to air pollution in pregnancy and childhood can have lifelong detrimental health consequences. The evidence suggests that there is no safe level of exposure to particulate matter, and especially to very small particles ($PM_{2.5}$) which penetrate into the lungs. Many studies highlight the possible under-estimates of the health effects of traffic-related air pollution and noise, due to problems in isolating these from other effects on health.

Evidence from both Britain and North America suggests that the most deprived communities experience the worst environmental degradation. The conclusion of Jerrett et al's Canadian study (2001) suggests that *"the largest health benefits would accrue … from reducing pollution in areas where it is worst and where social deprivation is largest"*, whilst Walker et al (2003) recommend that the Environment Agency *"should identify critical 'poverty-pollution' areas, and support efforts to* *improve air quality in these areas."* The implications for policy therefore would seem to be to target measures to reduce air pollution in deprived areas and highly populated urban areas, where the relatively small individual health benefits can make a big impact because they reach a large population. Concerns about the U.K.'s ability to meet current targets to reduce air pollution, particularly in urban areas, further emphasise the need for reducing motor vehicle traffic but at the same time enhancing alternatives such as walking, cycling, and public transport.

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Glossary

$\mu g/m^3$	micrograms per cubic metre
0_3	ozone
Asthma	The respiratory tract of patients with this ailment is highly sensitive to a wide variety of irritations.
Bronchitis	Irritation of the bronchial tubes; acute inflammation may be associated with colds
CAFÉ	Clean Air for Europe programme
CCS	Central London Congestion Charging Scheme.
CHD	coronary heart disease
Chronic bronchitis	Chronic inflammation of the bronchial tubes is diagnosed when there is coughing and sputum on most days for a period of at least 3 months for 2 consecutive years.
CO	carbon monoxide, an air pollutant primarily associated with road transport.
COMEAP	UK Department of Health's Committee on the Medical Effects of Air Pollutants
COPD	chronic obstructive pulmonary (lung) disease (such as chronic bronchitis, pulmonary emphysema, asthma)
Defra	Department for Environment, Food and Rural Affairs (UK)
DfT	Department for Transport
EAHEAP	Department of Health Ad-Hoc Group on the Economic Appraisal of the Health Effects of Air Pollution.
EEA	European Environment Agency
Emissions	Emanations of pollution at the source.
Epidemiology	Study of the analysis of the distribution of illnesses, physiological variables and social consequences of illnesses in human population groups, and factors influence this distribution.
EU	European Union
Euro (1-5)	European Commission emission standard legislation, relating to Euro standards I to V.
Ex Ante	Appraisal of a policy before implementation.
Ex Post	Appraisal of a policy after implementation.

Exacerbation	Acute attacks in the course of existing illness.
External costs	Costs borne not by those responsible for them, but by others.
Incidence	The number of new cases of illness per unit of time (usually 1 year) in a defined population, as a proportion of that population.
Internal costs	Costs borne by those responsible for them.
IOM	Institute of Occupational Medicine
IPC	Integrated Pollution Control
LEZ	Low Emission Zone
LRS	lower respiratory syndromes
Morbidity	Measure of the frequency of an illness in the population without distinguishing between incidence and prevalence.
Mortality	Number of person who died in a population as a proportion of that population.
NO	nitric oxide
NO_2	nitrogen dioxide
NOx	oxides of nitrogen (includes NO and NO_2)
PM_{10}	particulate matter with an aerodynamic diameter of 10 μg or less
$PM_{2.5}$	particulate matter with an aerodynamic diameter of 2.5 μg or less
PM	particulate matter - Primary particles are directly emitted into the atmosphere through man-made and natural processes. Man-made processes include combustion from car engines (both diesel and petrol), solid fuel combustion in households, industrial activities, erosion of roads by traffic, abrasion of brakes and tyres, and work in caves and mines. Secondary particles are formed in the air through chemical reactions, e.g. of nitrogen oxides (mainly emitted by traffic and some industrial processes), and sulphur dioxide (from the combustion of sulphur-containing fuels). Secondary particles are mostly found in the fine PM fraction.
Prevalence	Number of cases of a given illness at a specific time as a proportion of the population.
RAD	restricted activity day (day when a person needs to stay in bed)
Respiratory tract symptoms	Coughing and/or sputum independent of cold symptoms.
SO_2	sulphur dioxide

VOC	volatile organic compounds
VOLY	value of a life year
VSL	value of statistical life
WHO	World Health Organization
WTP	willingness to pay