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The Health Costs of Inaction with Respect to Air Pollution

Pascale Scapecchi

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THE HEALTH COSTS OF INACTION WITH RESPECT TO AIR POLLUTION

By Pascale Scapecchi

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ABSTRACT

How much does the environment affect human health? Is air pollution shortening our lives and those of our children? These questions are fundamental to environmental policies. Air pollution is a major environmental health threat in OECD countries, contributing to a number of illnesses, such as asthma, cancer and premature deaths. Despite national and international interventions and decreases in major emissions, the health impacts of air pollution are not likely to decrease in the years ahead, unless appropriate action is taken. This report presents estimates of the costs and benefits of environmental policies aiming at reducing air pollution and provides policy recommendations in order to better address environmental health issues.

JEL codes: D61, D62, H43, I18, Q51, Q53.

RÉSUMÉ

Dans quelle mesure l'environnement influe-t-il sur la santé humaine ? La pollution de l'air va-t-elle restreindre notre espérance de vie et celle de nos enfants ? Ces questions sont fondamentales pour les politiques environnementales. Dans les pays de l'OCDE, la pollution atmosphérique constitue une menace pour la santé, puisqu'elle joue un rôle dans nombre d'affections, telles que l'asthme, certains cancers et de décès prématurés. En dépit des actions engagées à l'échelle nationale et internationale et de la baisse des principales émissions, il est peu probable que les effets de la pollution de l'air sur la santé diminuent dans les années à venir à moins que ne soient prises les mesures qui s'imposent. Ce rapport présente des estimations des coûts et bénéfices de politiques environnementales visant à réduire la pollution atmosphérique et propose des recommandations politiques afin de mieux traiter les questions de santé environnementale.

Codes JEL: D61, D62, H43, I18, Q51, Q53.

FOREWORD

This document is a background report for the Health Chapter of *OECD Environmental Outlook to 2030* (www.oecd.org/environment/outlookto2030, published in March 2008) as well as the OECD Environment Directorate's project on the "Costs of Policy Inaction" with respect to environmental policy (www.oecd.org/env/costofinaction). It was drafted by Dr. Pascale Scapecchi (OECD Environment Directorate). It complements background papers on costs of inaction with respect to water pollution. The final OECD report on *Selected Environmental Policy Challenges: the Cost of Inaction* will be published in late 2008.

It represents the views of the author and does not necessarily reflect the official views of the Organisation or of the governments of its member countries.

This working paper is published on line as an OECD Environment Working Paper "The Health Costs of Inaction with respect to Air Pollution", OECD 2008. The full report can be accessed from: www.oecd.org/env/workingpapers.

For more information about this OECD work, please contact the project leader: Nick Johnstone (email: nick.johnstone@oecd.org).

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EXECUTIVE SUMMARY

Environmental health is a major concern in OECD countries

The links between a polluted environment and public health have been known for many years. However, early public health programmes concentrated more on the health *effects* rather than on the *causes* of ill-health, such as a deteriorated environment. The adoption of Agenda 21 at the United Nations Conference on Environment and Development (3-14 June 1992, Rio de Janeiro, Brazil) raised policy awareness on environmental health determinants (impact of pollution and resource depletion on human health).

Local outdoor air pollution is a major environmental problem in OECD countries. Its health effects can be either acute (*i.e.* resulting from short-term exposure) or chronic (*i.e.* resulting from long-term exposure). They range from minor eye irritation to upper respiratory symptoms, chronic respiratory diseases, cardiovascular diseases and lung cancer, and may result in hospital admission or even death (WHO, 2004).

The severity of individual effects will depend on the pollutant's chemical composition, its concentration in the air, the length of exposure, the synergy with other pollutants in the air, as well as individual susceptibility. Although environmental risk factors can affect the health of the whole population, some groups are indeed particularly vulnerable to environmental pollution, including children, pregnant women, the elderly and persons with pre-existing diseases. More recently, the literature on children's environmental health has also highlighted the specific vulnerability of children to air pollution, as well as increased infant mortality in highly polluted areas.

Air pollution is responsible for a growing number of premature deaths and life years lost

Evidence suggests that health impacts associated specifically with particulate matter (PM) pollution can be rather substantial. At the global level, PM pollution is estimated to be responsible each year for approximately 800 000 premature deaths (*i.e.* 1.4% of all global deaths) and 6.4 million years of life lost (*i.e.* 0.7% of total years of life lost; Cohen *et al*., 2004). The burden of disease attributable to outdoor air pollution is most important in developing countries, causing 39% of years of life lost in south-east Asia (*e.g.* China, Malaysia, and Viet Nam) and 20% in other Asian countries (*e.g.* India, and Bangladesh).

Outdoor air pollution is also significantly affecting children. In European countries with low levels of child mortality but high adult mortality rates, air pollution is estimated to be responsible for 2.4% of deaths from acute respiratory infections and 7.5% of all-cause mortality, among children 0-4 years of age (Valent et al, 2004). In addition, about 26.6% of all-cause deaths are attributable to the following environmental factors: outdoor air pollution (6.4%), indoor air pollution (4.6%), water sanitation and hygiene (9.6%) and injuries (6%).

PM_{10} and $PM_{2.5}$ – PM with a diameter less than 10 and 2.5 microns respectively – are especially harmful to human health as they can substantially reduce life expectancy. For the year 2000, it is estimated that exposure to PM_{10} caused approximately 350 000 premature deaths and 3.6 million years of life lost in Europe (AEA Technology Environment, 2005). The largest contribution to premature deaths for adults is from cardiopulmonary diseases.

A review of efficient environmental policies targeting air pollution

Governments have different policy options for improving air quality, such as regulating fuel quality or imposing stringent standards on emissions of specific air pollutants. Transport policies may also be changed in order to better internalise their effects on health and the environment.

This report presents a review of different efficient policy alternatives for reducing air pollution. France and Mexico, for example, tested out the effectiveness of putting particle filters on private and public vehicles (see Masse, 2005 for the France study, and Stevens et *al*., 2005 for the Mexican study). In both countries, these interventions were found to induce significant health benefits, which were largely greater than their costs.

Different air pollution abatement policies elsewhere have been evaluated. For example, the US Clean Air Act which proposed further control requirement of six major pollutants: PM_{10}, $PM_{2.5}$, NO_x, SO_2, CO and VOC, resulting in reduced air pollution, is considered as an efficient policy intervention with four dollars of benefits for every dollar of cost (US EPA, 1999).

In Canada, a cost-benefit analysis was conducted by Pandey *et al.* (2003) to determine the most efficient air-quality options. The study estimated that introducing Canada-wide standards for PM_{10}, $PM_{2.5}$ and ozone in Canada would result in net benefits of USD 3.6 billion per year.

In Europe, different scenarios of air pollution abatement under the EC Clean Air for Europe programme were evaluated (AEA Technology Environment, 2005). The estimations suggested that reducing air pollution in Europe slightly more than is currently done would generate net benefits of between USD 41 billion and USD 132 billion over 20 years.

A cost-benefit analysis was also undertaken in Mexico City to determine the efficiency of an ultra-low sulphur fuels policy (Blumberg, 2004). It projected that substantial health benefits were associated with a reduction in sulphur content of fuels. Moreover, this policy intervention would be efficient with annual benefits significantly larger than corresponding annual costs (respectively USD 9 700 million and USD 648 million).

Although there is a wide variation between these policy interventions in terms of their benefit-cost ratio (BCR), some lessons can be learned from these experiences:

1. Less stringent policies can be very effective (*e.g.* the *EU Thematic Strategy on Air Pollution*)

2. "Simple" policies can sometimes be the most efficient (*e.g.* ultra-low sulphur fuel policies)

3. There is evidence of a learning effect: policies introduced recently benefit from the experience of policies introduced elsewhere a few years earlier.

4. Policies targeting several pollutants at the same time are more efficient than single-pollutant policies, suggesting opportunities for economies of scope in abatement policies.

5. Benefits vary across countries, mainly because of GDP differences.

6. A comparison of *ex ante* and *ex post* evaluations of environmental policies suggests that *ex ante* costs are often overestimated, while *ex ante* benefits are underestimated due to information failures, partly as a result of strategic behaviour by involved industries.

These examples suggest that policies which improve air quality are often cost-efficient: the benefits outweigh the costs. Reductions in PM air pollution levels are highly beneficial in health terms, probably due to the relatively strong link that exists between PM exposure and premature mortality. The fact that most of these cost-benefit analyses only consider the health impacts of specific interventions suggests that total benefits (including benefits to the economy and the environment as well) may be underestimated.

What should be done to further reduce environmental health impacts?

The economic evidence shows that there are opportunities for significant net benefits in limiting air pollution (and more generally environmental degradation), not only for human health, but also for the economy. This finding is particularly true for those OECD and non-OECD countries which have significant levels of air pollution. As an example, two recent studies highlighted the significance of the economic burden of air pollution, whose costs represent 0.7% of the US GDP (Muller and Mendelsohn, 2007) and 3.8% of China GDP (The World Bank, 2007).

OECD countries should therefore:

- Strengthen their efforts to further reduce outdoor air pollution emissions to levels below the WHO guidelines (WHO, 2006) to limit populations' exposure. Such efforts could include more stringent legislation and implementation of appropriate pollution control policies, cleaner and more efficient energy policies and environmentally sustainable transport policies.

- Expand international initiatives to better tackle issues related to the transboundary nature of air pollution (*i.e.* air pollution generated in a country can have consequences in neighbouring countries).

- Apply a more integrated approach to better address environmental health issues, such as trans-national initiatives proposed by the WHO (*National Environmental Health Action Plan*) and the EC (*European Environment and Health Strategy*), to complete environmental policies with other types of interventions which will greatly improve both air quality and health.

Given the rapid rise in transport and energy use in non-OECD countries, air pollution levels are anticipated to continue to increase, resulting in a growing number of health problems in these countries. Finally, emerging environmental challenges, such as climate change, may result in new, significant damages on human health in the near future.

Without sufficient efforts, the costs of healthcare from environmental pollution are likely to become greater in the years to come. Appropriate environmental policies should therefore be implemented in order to address those environmental issues that cause the strongest effects on human health.

THE HEALTH COSTS OF INACTION WITH RESPECT TO AIR POLLUTION

1. Introduction

Health costs have risen over time and in most countries health expenditures have increased at a faster rate than overall economic growth. In 2003, OECD countries devoted on average 8.8% of their GDP to health spending, up from 7.1% in 1990[1]. Although it is difficult to estimate the amount of expenditures associated with environmental degradation, it is reasonable to consider that environment-related health costs have also increased.

Population ageing contributes to the growth in health spending. The percentage of the population of 65 years or older has risen in all OECD countries and this is expected to continue in the years ahead, given the ageing of the "baby-boom" generation. Since older populations tend to be in greater need of health care, health expenditures are likely to increase. The greater vulnerability of older people to the impacts of air pollution contributes to this increased demand for health services.

The leading causes of death in OECD countries in 2001-2002 were related to cardiovascular diseases, cancer, diseases of the respiratory system, and external causes of deaths (*e.g.* accidents, suicides, falls, and homicides) (OECD, 2005). As described in WHO (2004), these health outcomes can be, in some measures, attributable to exposure to air pollution. On the morbidity side, prevalence of asthma and allergies, in particular among children, has been steadily increasing in most OECD countries since 1995. As such, environmental degradation, and more particularly air pollution, may be a significant contributor to ill-health and death in OECD countries. A recent analysis at the global level estimates that outdoor air pollution is responsible for approximately 800,000 premature deaths (*i.e.* 1.2% of global deaths) and 6.4 million years of life lost (*i.e.* 0.5% of total years of life lost) per year (Cohen *et al.*, 2005).

Given the importance of health impacts associated with air pollution in mortality and morbidity terms, this report focuses on air pollution. The objective of this report is to provide background information on the health costs of air pollution. In particular, it proposes a review of the economic studies that provide estimates of the benefits of reducing air pollution. Although the approach chosen in this report may suffer from methodological problems (see for example Hausman, 1993), it nevertheless appears as the most appropriate in the context of valuing the health benefits of reducing air pollution. The analysis of these methodological issues is beyond the purpose of this report.

The report is organised as follows. The second section presents the underlying environmental problem. Health impacts of air pollution are described in the third section. Then, estimates of the costs and benefits of environmental policies with the objective of reducing air pollution, *i.e.* improving air quality, are provided, suggesting that prevention of environment-related diseases should be strengthened. Concluding remarks close the report.

[1] Source: OECD Health Data, 2006.

2. Environmental problems

2.1 Description

Important quantities of potentially noxious pollutants are emitted every day in the ambient air and cause damages both to the natural environment and to human health. Two types of air pollutants can be distinguished: suspended particulate matter (dust, emissions, smog and smoke) and gaseous pollutants (gases and vapour). Different factors can affect the concentration of air pollutants. Local concentrations of pollutants depend on the quantity in pollutants of the emitting source (fixed or mobile) as well as on the dispersion of these pollutants. Weather conditions affect the daily variations in concentrations – *i.e.* photochemical smog is a function of sunlight. Wind is also very important factor in the dispersion of air pollutants. Air pollution is a cocktail of several pollutants. Most key air pollutants include particulate matter (PM), carbon monoxide (CO), carbon dioxide (CO_2), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), volatile organic compounds (VOC) and ozone (O_3). Air pollution is caused by both natural and anthropogenic sources. The sources of pollutants in ambient air can be either mobile or fixed.

Natural sources of ambient air pollution include SO_2 and NO_2 emissions from volcanoes, oceans, biological decomposition, firestorms and wildfires, VOCs and pollen from trees and other types of flora, as well as PM from dust storms and wildfires (WHO, 2004).

Significant anthropogenic sources of ambient air pollution include industries, transport, and power generation[2]. The most common source of air pollution comes from the burning of fossil fuels in power stations, industries, buildings and houses, and road traffic. Fossil fuel combustion is responsible for emissions of NO_2, SO_2, CO, PM, VOC and lead as well. Other sources include wildfires, chemical products, fertiliser and paper production as well as waste incineration. In Europe, the greatest contributors to emissions of primary PM_{10} and gases leading to the formation of secondary PM_{10} in 2000 were the energy-production (30%), road-transport (22%), industrial (17%) and agricultural (12%) sectors (Krzyzanowski et al., 2005).

These pollutants are referred to as "primary" pollutants as they have direct sources. However, this is not the case of O_3: there is no direct source of ground-level O_3. O_3 is the result of a photochemical reaction of sunlight on VOCs, in the presence of NO_2. As such, O_3 is referred to as a "secondary" pollutant. There are also indirect sources of PM emissions, created by the combination with other gases such as NOx (nitrates) and SOx (sulphates). Therefore, PM pollution can be considered either as a primary or secondary pollutant.

Primary and secondary pollutants have diverse effects on human health, more or less harmful. Fuel combustion is the primary source of health-damaging air pollutants, including fine and respirable particulate matter ($PM_{2.5}$ and PM_{10}), CO, SO_2, O_3, etc (WHO, 2004). This multi-pollutant characteristic of air pollution complicates both measurement and the design of policy interventions. Indeed, relationships between the various air pollutants are not known with perfect certainty, and a policy with the objective of reducing emissions of PM may have an adverse impact in increasing emissions of another pollutant. In addition, there is no harmonised measurement system used in OECD countries and some pollutants, such as NO_2, PM and SO_2, are more commonly measured and monitored than others. Scientific uncertainty and deficiencies in data quality complicates the assessment of the health damages associated with air pollution. To this end, it is common practice to use PM measures as a proxy for air pollution, mainly for two reasons: PM pollution is monitored and measured in most OECD countries and PM has been consistently associated with (the most) serious effects on human health, in particular with its undeniable effects on mortality.

[2] In the European Union, road transport and energy industry contribute to 27% of the total emissions of PM10 (Krzyzanowski et al., 2005).

2.2 Air quality trends

Significant concerns relate to the effects of air pollution on human health, ecosystems, and buildings, and to their economic and social consequences. Monitoring and measurement of air pollution emissions are therefore key instruments to support environmental policymaking.

Figures presented in Table 1 are derived from OECD collection of environmental data from Member countries' governments (OECD, 2005). Table 1 provides trends in anthropogenic emissions of major air pollutants for OECD countries. The figures refer to the major categories of emission sources for these pollutants: mobile sources (motor vehicles, etc.) and stationary sources, which include power stations, fuel combustion (industrial, domestic, etc.), industrial processes (pollutants emitted in manufacturing); and miscellaneous sources such as waste incineration, agricultural burning, etc. Table 1 presents emissions of SO_x, NO_x, CO, VOC and PM in 1990 and 2002 in OECD countries.

Table 1. Emissions of major air pollutants in OECD countries in 1990 and 2002 (unit: thousand tones) and variation (Δ) between 1990 and 2002

Air pollutant	SO_x			NO_x			CO			VOC			PM		
Country	1990	2002	Δ (%)	1990	2002	Δ (%)	1990	2002	Δ (%)	1990	2002	Δ (%)	1990	2002	Δ (%)
Australia	1636	2803	**71**	1405	1691	**20**	5742	4896	**-15**	1107	1034	**-7**			
Austria	80	36	**-55**	207	200	**-3**	1249	812	**-35**	296	191	**-36**	25.5	26	**3**
Belgium	355	151	**-57**	365	290	**-20**	1470	1024	**-30**	344	216	**-37**		34	
Canada	3260	2394	**-27**	2615	2459	**-6**	13105	9761	**-26**	2844	2615	**-8**		890	
Czech Republic	1876	237	**-87**	544	318	**-42**	1257	546	**-57**	435	203	**-53**	565		
Denmark	176	24	**-86**	276	191	**-31**	744	575	**-23**	163	122	**-25**		14	
Finland	237	85	**-64**	311	211	**-32**	549	592	**8**	236	151	**-36**		39	
France	1326	537	**-60**	1895	1350	**-29**	10885	5882	**-46**	2368	1412	**-40**	337	251	**-26**
Germany	5326	611	**-89**	2745	1417	**-48**	11212	4311	**-62**	3591	1478	**-59**	1840	209	**-89**
Greece	491	509	**4**	287	318	**11**	1220	1166	**-4**	257	268	**4**			
Hungary	1010	359	**-64**	238	180	**-24**	767	620	**-19**	205	155	**-24**		24	
Iceland	8.2	10.1	**22**	26.6	26	**-2**	45	22	**-50**	12.6	8	**-39**			
Ireland	183	96	**-48**	116	121	**5**	397	251	**-37**	106	78	**-27**		11	
Italy	1773	665	**-63**	1927	1267	**-34**	7049	4476	**-37**	2028	1339	**-34**			
Japan	1001	857	**-14**	2052	2018	**-2**	4064	3453	**-15**	1963	1761	**-10**	171		
Korea	1611			925			1991			856	1760	**106**	420		
Luxembourg	14.7	3	**-80**	23.3	17	**-27**	175.5	49	**-72**	18.9	11	**-44**			
Mexico				974			8920								
Netherlands	204	85	**-58**	599	430	**-28**	1130	656	**-42**	490	244	**-50**	48	28	**-41**
New Zealand	61	68	**10**	138	204	**48**	525	696	**33**	133.6	173	**30**	37		
Norway	52	22	**-58**	224	213	**-5**	867	530	**-39**	294	345	**17**	62	55	**-11**
Poland	3210	1455	**-55**	1280	796	**-38**	7406	3410	**-54**	831	568	**-32**			
Portugal	322	295	**-9**	255	288	**13**	835	728	**-13**	266	307	**15**			
Slovak Republic	542	102	**-81**	216	102	**-53**	493	297	**-40**	252	87	**-65**		16	
Spain	2178	1541	**-29**	1256	1432	**14**	3798	2734	**-28**	1164	1155	**-1**		149	
Sweden	106	58	**-45**	324	242	**-25**	1202	766	**-36**	503	295	**-41**	86	45	**-47**
Switzerland	45	19	**-58**	167	90	**-46**	770	383	**-50**	293	139	**-53**	36		
Turkey	1590	2112	**33**	643	961	**48**	3585	3779	**5**	463	726	**57**			
UK	3722	1003	**-73**	2775	1587	**-43**	7412	3234	**-56**	2420	1187	**-51**	173	93	**-46**
USA	20925	13847	**-34**	22830	18833	**-18**	130277	87454	**-33**	20979	14298	**-32**	6858	5581	**-19**

Source: OECD (2005)

Emission intensities for SO_x show significant variations among OECD countries, depending on individual economic structure and energy consumption patterns, among other determinants. Over the past 10 years, emissions of acidifying substances and other air pollution have continuously declined throughout the OECD. Compared to 1990 levels, SO_x emissions have decreased significantly in all but a few countries, mainly because of successful decoupling of fossil fuel use from economic growth (OECD, 2004). European countries have in general achieved more significant reductions in SO_x emissions because of earlier commitments. The Gothenburg Protocol adopted in Europe and North America should further reduce SO_x emissions in the years ahead.

Reduction of NO_x emissions have been less important and have arisen more recently, suggesting only a weak decoupling from GDP compared to 1990 (OECD, 2004). Important variations in NO_x emission intensities over time can be observed among OECD countries. NO_x emissions reductions have been particularly significant in many European countries over the last decade, because of the Sofia Protocol designed to stabilise NO_x emissions by the end of 1994 to their 1987 levels. However, some European OECD countries have not yet met these objectives, and the achievement of further reductions, as described in the Gothenburg Protocol, will require additional efforts.

CO emissions have drastically decreased over the last decade. Some OECD countries have been more active than others, in particular in Europe. CO levels in ambient air have decreased mostly as the results of the introduction of new standards and equipment in transport and manufacturing. Examples include the introduction of catalytic converters for cars, and stricter standards for fuel quality specifications for petrol and diesel fuels (EURO IV and V). These policies have also implied a significant decrease in VOC emissions. However, additional measures will have to be undertaken to meet the objectives of the Gothenburg Protocol (reduce VOC emissions by 56% in 2010 in relation to 1990 level of emissions).

PM_{10} emissions have significantly decreased, in particular in European OECD countries. There, emissions of PM_{10} are expected to be further reduced in the years ahead as improved vehicle engine technologies are being adopted (Euro V) and stationary fuel combustion emissions are controlled through the abatement or use of low-sulphur fuels such as natural gas.

The main challenges are to further reduce emissions of local and regional air pollutants in order to achieve a strong decoupling of emissions from GDP and to limit the exposure of the population to air pollution. This implies implementing appropriate pollution control policies, technological progress, energy savings and environmentally sustainable transport policies (OECD, 2004).

Measurement and monitoring of population exposure to air pollution concentrations are also important aspects of environmental policymaking. Human exposure is particularly high in urban areas where economic activities and road traffic are concentrated. Causes of growing concern are concentrations of fine particulates, NO_2, toxic air pollutants, and acute ground-level ozone pollution episodes in both urban and rural areas.

Table 2 provides 2002 concentrations in selected air pollutants, for OECD countries. Note that average urban PM_{10} concentrations were estimated in residential areas of cities larger than 100,000 (World Bank, 2006).

Table 2. Air pollution concentrations in PM_{10}, SO_2 and NO_2, for 2002

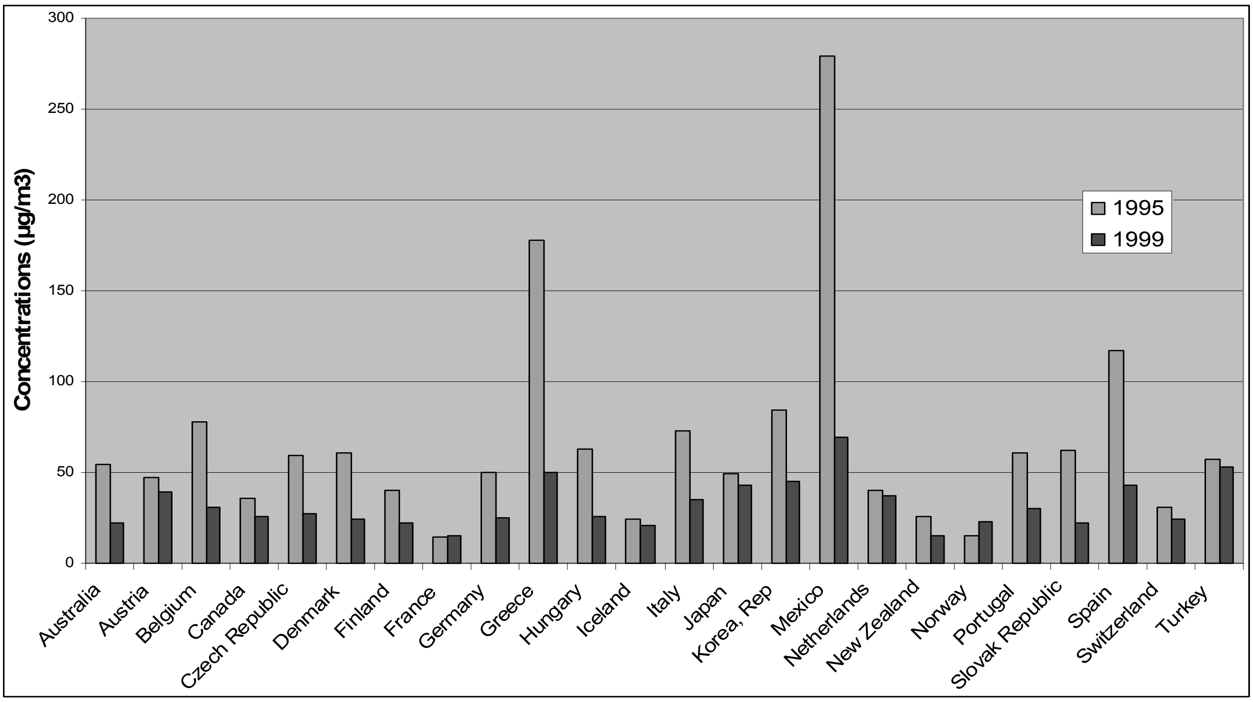
Countries	City	Average annual concentration of PM_{10}, µg/m^3	Average annual concentration of SO_2, µg/m^3	Average annual concentration of NO_2, µg/m^3
Australia	Melbourne	13		30
	Perth	13	5	19
	Sydney	22	28	81
Austria	Vienna	44	14	42
Belgium	Brussels	30	20	48
Canada	Montreal	20	10	42
	Toronto	24	17	43
	Vancouver	14	14	37
Czech Republic	Prague	25	14	33
Denmark	Copenhagen	23	7	54
Finland	Helsinki	23	4	35
France	Paris	12	14	57
Germany	Berlin	25	18	26
	Frankfurt	22	11	45
	Munich	22	8	53
Greece	Athens	51	34	64
Hungary	Budapest	23	39	51
Iceland	Reykjavik	20	5	42
Ireland	Dublin	21	20	
Italy	Milan	36	31	
	Rome	35		
	Torino	53		
Japan	Osaka	37	19	63
	Tokyo	42	18	68
	Yokohama	32	100	13
Korea	Pusan	44	60	51
	Seoul	46	44	60
	Taegu	50	81	62
Mexico	Mexico City	55	74	130
Netherlands	Amsterdam	40	10	58
New Zealand	Auckland	15	3	20
Norway	Oslo	19	8	43
Poland	Lodz	39	21	43
	Warsaw	43	16	32
Portugal	Lisbon	28	8	52
Slovakia	Bratislava	19	21	27
Spain	Barcelona	43	11	43
	Madrid	37	24	66
Sweden	Stockholm	13	3	20
Switzerland	Zurich	26	11	39
Turkey	Ankara	54	55	46
	Istanbul	64	120	
UK	Birmingham	26	9	45
	London	23	25	77
	Manchester	17	26	49

US	Chicago Los Angeles New York	26 36 22	14 9 26	57 74 79
EU		6.33	27.73	34.03

Source: World Bank (2006).

Despite significant decreases in concentrations of air pollutants in most OECD countries over the last decade, air pollution remains a major concern, in particular in developing countries. Many cities in OECD countries still suffer from high levels of PM, NO_2 and SO_2 pollution. Populations in Mexico, Greece and Turkey are particularly exposed to high levels of PM_{10} concentrations in ambient air (see Figure 1).

Figure 1 – Trends in PM_{10} concentrations in selected OECD countries



Source: World Bank (2006).

At the global level, Schwela and Gopalan (2002) estimated that about 1,200 million people are exposed to excessive (*i.e.* relative to WHO guidelines – see below) levels of SO_2 and approximately 1,400 million people are exposed to excessive levels of smoke and PM. In addition, 15 to 20 % of Europeans and North Americans are exposed to excessive levels of NO_2, and excessive levels of CO persist in half of the world's cities. However, developing countries are the most affected by air pollution. For example, India is the country where the highest concentrations in PM are observed: 145 $\mu g/m^3$ in Calcutta, 177 $\mu g/m^3$ in Delhi (world's highest concentration), 128 $\mu g/m^3$ in the region of Kanpur and Lucknow. Chinese populations' exposure to NO_2, SO_2 and PM is particularly alarming. Indeed, levels of concentrations in many cities in China are above 100 $\mu g/m^3$. Concerning SO_2 concentrations, world highest concentrations are observed in Guiyang (424 $\mu g/m^3$), Chongguing (340 $\mu g/m^3$) and Taiyuan (211 $\mu g/m^3$). Levels of PM concentrations are also very high: 139 $\mu g/m^3$ in Taijin, 137 $\mu g/m^3$ in Chongguing and 112 $\mu g/m^3$ in Shenyang. Finally, NO_2 concentrations are also among the highest: 136 $\mu g/m^3$ in Guangzhu, 122 $\mu g/m^3$ in Beijing and 104 $\mu g/m^3$ in Lanzhou. South-east Asia is therefore the world region where populations are exposed to the highest concentration levels of air pollutants in the world.

These concentration levels significantly exceed WHO guidelines on air quality (WHO, 2005), which recommend the following ranges of values:

- $PM_{2.5}$: 10 µg/m^3 annual mean;
- PM_{10}: 20 µg/m^3 annual mean;
- O_3: 100 µg/m^3 for daily maximum 8-hour mean;
- NO_2: 40 µg/m^3 annual mean; and,
- SO_2: 20 µg/m^3 for 24-hour mean.

Despite significant decreases in concentrations and emissions of air pollutants in most OECD countries over the last decade, air pollution remains a major concern, in particular in developing countries. This could be explained partly by the multi-pollutant and complex nature of air pollution. The main policy concern associated with air pollution is its adverse impacts on the environment, on the buildings, and on fauna and flora. The section below provides a description of air pollution-related health effects, as well as estimated health damages associated with PM pollution.

3. Health impacts of air pollution

3.1 Description of the health impacts of air pollution

Recent epidemiological studies have highlighted the relationship between outdoor air pollution and acute and chronic effects on health, including premature death and additional hospital admissions (WHO, 2004). Different pollutants can lead to respiratory problems, exacerbated allergies, and adverse neurological, reproductive, and developmental effects as well. This is especially true for vulnerable populations such as children, the elderly, pregnant women, persons with pre-existing health conditions, such as heart or lung disease, and people with weakened immune systems. People who work or exercise outdoors may also be especially sensitive.

The health effects of air pollution are commonly separated into short-term effects (acute) and long-term effects (chronic). The health effects range anywhere from minor irritation of eyes and the upper respiratory system to chronic respiratory disease, heart disease, lung cancer, and death. They depend on the pollutant type, its concentration in the air, the length of exposure, the presence of other pollutants in the air, as well as individual susceptibility.

The short-term effects of exposure to PM, SO_2, NO_2 and other air pollutants include increased respiratory morbidity, a higher rate of hospital admission for respiratory and cardiovascular diseases and mortality. The long term effects of exposure to these air pollutants include increased mortality and reduced life expectancy of the entire population. Both short-term and long-term exposures have also been linked with premature mortality and reduced life expectancy, in the order of 1-2 years (WHO, 2004).

More specifically, a large number of epidemiological studies have demonstrated the links between short and long-term exposure to PM, especially fine particles (alone or in combination with other air pollutants), and a number of significant health problems, including: premature death; respiratory-related hospital admissions and emergency room visits; cardiovascular hospital admissions; aggravated asthma; acute respiratory symptoms, including aggravated coughing and difficult or painful breathing; chronic bronchitis; and, restricted activity days (WHO, 2004). Numerous studies have attempted to quantify the number of deaths that can be attributed to fine PM pollution ($PM_{2.5}$). Examples will be provided in the next section.

SO_2 and NO_2 can affect health in different ways. They can be directly toxic to the respiratory system and can have adverse effects on lungs. Combined with water, NO_2 forms acid that damages the lung tissue. In addition, SO_2 and NO_2 can combine to form fine PM pollution, and therefore have related health effects (WHO, 2004).

VOCs are associated with cancers as well as adverse neurological, reproductive and developmental impacts on human beings. In the presence of NOx, they form O_3 (WHO, 2004).

Exposure to elevated O_3 levels can have many adverse health impacts, including coughing, shortness of breath, pain when breathing, lung and eye irritation, and greater susceptibility to respiratory illnesses such as bronchitis and pneumonia. O_3 is also thought to exacerbate asthma attacks and therefore be responsible for increased hospital admissions and emergency room visits for asthma. Finally, epidemiological studies have also demonstrated a relationship between O_3 and pulmonary inflammation, reduced lung capacity, increased susceptibility to respiratory infections, and increased risk of hospitalization and early death (WHO, 2004).

Table 3 summarises the important health effects associated with specific pollutants.

Table 3. Health effects associated with selected air pollutants

Pollutant	Short-term effects	Long-term effects
PM	- Lung inflammatory reactions - Respiratory symptoms - Cardiovascular effects - Increase in medication use - Increase in hospital admissions - Increase in mortality	- Increase in lower respiratory symptoms - Reduction in lung function in children and adults - Increase in chronic obstructive pulmonary disease - Increase in cardiopulmonary mortality and lung cancer
O_3	- Effects on pulmonary function - Lung inflammatory reactions - Respiratory symptoms - Increase in medication use - Increase in hospital admissions - Increase in mortality	- Reduction in lung function development
NO_2	- Effects on pulmonary function (asthmatics) - Increase in airway allergic inflammatory reactions - Increase in hospital admissions - Increase in mortality	- Reduction in lung function - Increased probability of respiratory symptoms

Source: WHO (2004).

Different people are affected by air pollution in different ways, and some sub-populations are more at risk than others. Their specific vulnerability can result from genetic conditions but it also depends on their living environment, their lifestyle, etc. The whole urban population can be affected by long-term exposure to air pollution. However, epidemiological evidence suggests that the very young and very old people, and people with pre-existing respiratory disease and other ill health are particularly at risk. Air pollution has been shown to cause acute respiratory infections in children and chronic bronchitis in adults (EEA, 2002). Several pollutants, such as PM_{10}, $PM_{2.5}$, O_3, NO_2 and SO_2, can aggravate the frequency and the severity of attacks of asthmatic children and adults. In addition, those pollutants increase the frequency and the severity of airway infections in children. Air pollution is also believed to aggravate child and post-natal mortality (such as sudden infant death syndrome) as well as lung development in children (EEA, 2002). It has also been shown that long-term exposure to air pollution can increase the probability of developing a cardiovascular or respiratory chronic disease, such as lung cancer (WHO, 2004).

3.2 Estimated health damages attributable to air pollution

3.2.1 Situation in OECD countries

In order to establish priorities in environment and health, policymakers need to have scientifically-based information. Indicators on the environmental state of the country, and on the health status of the population, provide information that can support efficient policymaking. However, quantification of health damages associated with air pollution is not straightforward. Firstly, there are other important contributors to ill-health, such as genetic predispositions, lifestyle or social conditions, and it is therefore difficult to separate out the influence of each attribute on specific health impacts. Secondly, the methods and systems used to measure population's exposure to air pollution differ widely across countries, some being more advanced than others. In addition, some countries measure, for instance, PM_{10} while others only measure $PM_{2.5}$. These considerations suggest that exposure data may not be 100% reliable. Thirdly, as mentioned above, vulnerability to air pollution is not homogeneous among the population and some people are more susceptible than others.

The objective of this section is to highlight the substantial health effects of PM-related air pollution in OECD countries. As such, a set of tables is provided, presenting number of observed cases associated with the health endpoints listed above, for most of the OECD countries (when such information is available).

Abt Associates (2000) estimated the health impacts of PM pollution from power plants in the US. They found that PM from power plants may shorten the life of 30,100 Americans and may be responsible for thousands of diseases of the respiratory system (see Table 4).

Table 4. Estimated health damages associated with power plants PM pollution in the US (2000)

Health endpoints	Mean attributable cases per year
Premature mortality	30,100
Chronic bronchitis	18,600
Hospital admissions – pneumonia	4,040
Hospital admissions – COPD	3,320
Hospital admissions - asthma	3,020
Cardiovascular hospital admissions	9,720
Emergency room visits for asthma	7,160
Asthma attacks	603,000
Acute bronchitis	59,000
Upper respiratory symptoms	679,000
Lower respiratory symptoms	630,000
Lost work days	5,130,000
Minor restricted activity days	26,300,000

A rather complete picture of EU countries situation with regards to air pollution impacts on health has been provided by the analysis of the Clean Air for Europe (CAFE) programme launched by the European Commission (EC) (AEA technology environment, 2005) (see Table 5). Indeed, this analysis quantifies estimated health impacts from both long-term and short-term exposures and includes both mortality and morbidity aspects. However, it only focuses on ozone and PM_{10} air pollution, given that these two air pollutants are considered to be most harmful to human health. At the EU level, PM pollution is associated with almost 350,000 premature deaths, corresponding to a loss of about 3,600,000 years of life. Selected estimated impacts quantified in the health analysis of the CAFE programme are presented in Table 5.

Table 5. Estimated health damages associated with PM pollution (year 2000) in European OECD countries

Health outcome	Chronic Mortality All ages	Chronic Mortality 30yr +	Infant Mortality 0-1yr	Chronic Bronchitis 27yr +	Respiratory Hospital Admissions	Cardiac Hospital Admissions	Restricted activity day (15-64yr)
Measure	Life years lost	Premature deaths	Premature deaths	Cases	Cases	Cases	Days
Austria	59,400	5,500	8	2,750	1,020	630	5,756,330
Belgium	137,370	12,880	24	6,260	2,350	1,450	12,863,530
Czech Republic	90,640	9,070	16	4,000	1,550	960	9,033,130
Denmark	30,690	3,270	4	1,400	530	320	2,925,110
Finland	13,840	1,270	2	620	237	146	1,323,390
France	482,210	42,090	112	21,220	8,260	5,100	44,935,660
Germany	756,850	75,040	110	35,800	12,970	8,000	73,588,300
Greece	71,280	7,230	12	3,270	1,220	750	6,864,590
Hungary	104,090	12,870	25	4,590	1,780	1,100	10,171,930
Ireland	14,630	1,170	4	570	251	155	1,403,960
Italy	497,840	50,690	76	23,820	8,530	5,260	48,105,300
Luxemburg	4,090	320	1	184	70	43	392,680
The Netherlands	184,160	15,540	33	8,310	3,160	1,950	17,869,290
Poland	356,350	32,850	94	14,680	6,110	3,770	34,944,700
Portugal	49,100	5,040	13	2,180	840	520	4,748,890
Slovakia	46,940	4,250	15	1,920	800	500	4,636,610
Spain	217,190	19,940	36	9,920	3,720	2,300	21,287,840
Sweden	32,960	3,280	4	1,490	560	350	3,027,120
United Kingdom	409,120	39,470	73	18,160	7,010	4,320	38,022,110
Total EU25	3,618,700	347,900	677	163,800	62,000	38,300	347,687,000

Source: AEA Technology Environment (2005).

These figures on selected health endpoints associated with PM pollution suggest that air pollution, and more particularly PM pollution, is an important concern in OECD European countries.

Similar figures are observed in other OECD countries. Mexico is for example another country where PM-related air pollution has important health impacts. Table 6 presents estimated annual adverse health impacts related to PM pollution in Mexico.

Table 6. Estimated health impacts associated with PM pollution in Mexico (2004)

Health endpoints	Observed cases
Premature mortality	2,068
Chronic bronchitis	1,370
Hospital admissions – pneumonia	274
Hospital admissions – COPD	224
Hospital admissions – asthma	224
Cardiovascular hospital admissions	673
Emergency room visits for asthma	523
Asthma attacks	44,000
Acute bronchitis	4,385
Minor restricted activity days	2,000,000

Source: Blumberg et al. (2004)

In Canada, Judek, Jessiman and Stieb (2004) estimate that the yearly number of excess deaths associated with short-term exposure to air pollution is around 1800 (± 700). The yearly number of excess deaths associated with long-term exposure to air pollution is 4200 (± 2000), although it might be necessary to wait for five years or more after having reduced the air pollution levels to completely prevent from those deaths. Therefore, the total estimate of excess deaths associated with air pollution therefore amounts to 5900 (± 2100). At the provincial level, the Ontario Medical Association (OMA, 2005) has produced a report that evaluates the damages for Ontario. In 2005 in this province, PM and ozone-related air pollution is responsible for 5,800 premature deaths, 16,800 hospital admissions, nearly 60,000 emergency room visits and over 29 millions minor illness days.

Hong et al. (1999) have estimated daily mortality associated with air pollution in Inchon (Korea). They found that 6.8 cardiovascular-related deaths per day and 1.2 respiratory-related deaths per day in Inchon could be related to air pollution (mean values). In addition, Ha et al. (2003) provide mean cases for air pollution-related respiratory and overall mortality, observed in Seoul, for the 1995-1999 period. These figures are reported in Table 7.

Table 7. Estimated air pollution-related causes of deaths in Seoul (Korea) in 1995-99

Mortality	Daily death (mean)	Total death
	All causes	
Post neonatal deaths	0.6	1,045
Deaths < 65	37.1	67,597
Deaths > 65	54.9	100,316
	Respiratory causes	
Post neonatal deaths	0.04	71
Deaths < 65	1.2	2,194
Deaths > 65	4.1	7,573

Source: Ha, et al. (2003)

In New Zealand, Fisher et al. (2002) have estimated the annual mortality due to air pollution exposures. They found that about 970 annual deaths can be attributable to PM_{10} pollution, among which 41% are related to air pollution from traffic.

All these examples and empirical evidence suggest that air pollution is a major problem in OECD countries. The health impacts associated in particular with PM pollution can be rather substantial. Mortality impacts are particularly important and significant in all OECD countries. PM-pollution is responsible for many deaths and for a large number of life years lost at the global level as well, as presented in the section below.

3.2.2 The epidemiological burden of disease of air pollution

Analyses at the global level have also highlighted significant health impacts in developing countries, expressed in terms of "burden of disease". The burden of disease is measured in terms of the disability-adjusted life year (DALY), a summary measure encompassing the impact of premature death (*i.e.* the number of years of life lost due to premature death, or YLL), and the health problems among those who are alive (*i.e.* the number of years lived with a disability, or YLD).

Drawing upon daily mortality data, Schwela and Gopalan (2002) have estimated that 4 to 8% of global premature deaths each year are due to exposure to outdoor and indoor PM, with respectively 500,000 and 2.5 million annual premature deaths. In addition, the study estimated that between 20 and 30% of all respiratory diseases could be caused by outdoor and indoor air pollution, the latter having a greater impact (Schwela and Gopalan, 2002).

Valent et al. (2004) estimate the burden of disease associated with outdoor air pollution in children of 0 to 4 years of age in Europe. Results are presented in Table 8. They indicate that a significant burden of mortality in children is attributable to outdoor air pollution, in particular in countries of the European region with low child and adult mortality (EUR B), and in countries with low child and high adult mortality (EUR C), where air pollution is estimated to be responsible for 2.4% of deaths from acute respiratory infections (ARI) and 7.5% of all-cause mortality, among children 0-4 years of age. In addition, about 26.6% of all-cause deaths are attributable to the following environmental factors: outdoor air pollution (6.4%), indoor air pollution (4.6%), water sanitation and hygiene (9.6%) and injuries (6%) (See Annex 1 for list of countries included in WHO regions.)

Table 8. Burden of disease associated with outdoor air pollution in children (0-4 years) in Europe

Sub-region	Outcome	Attributable deaths (central estimate)	Attributable fraction * (%)
EUR A	Deaths from all causes	178	0.8
EUR B		10617	7.5
EUR C		3001	5.8
EUR A	Deaths from ARI	3	<0.1
EUR B		3387	2.4
EUR C		471	0.9

*: Defined as the proportion of the outcome attributable to the exposure, using 20 µg/m3 as the target PM_{10} concentration.
Source: Valent et al. (2004)

Cohen et al. (2004) provide estimates of the number of years of life lost (YLL) and DALYs for cardiopulmonary disease, lung cancer, ARI and total mortality associated with urban air pollution at the global level. The results presented in Table 9 are expressed in thousands for the year 2000, disaggregated WHO world region (see Annex 1)[3].

Table 9. Burden of disease associated with air pollution (2000)

	Cardiopulmonary disease		Lung Cancer		Acute respiratory disease		Total		
Sub-region	YLL	DALYs	YLL	DALYs	YLL	DALYs	Deaths	YLL	DALYs
AFR-D	162	193	4	4	119	121	22	285	319
AFR-E	84	100	3	3	61	62	10	147	166
AMR-A	116	161	37	38	0	0	28	152	200
AMR-B	201	273	20	20	11	14	30	232	307
AMR-D	31	39	1	2	11	12	5	44	53
EMR-D	65	77	5	5	7	9	8	77	91
EMR-D	386	457	17	17	155	162	51	558	636
EUR-A	90	122	27	28	0	0	23	117	151
EUR-B	238	286	30	31	20	21	38	288	338
EUR-C	291	340	27	28	2	2	46	320	360
SEAR-B	240	291	22	22	21	25	32	282	339
SEAR-D	1 006	1 195	56	57	250	261	132	1 312	1513
WPR-A	65	95	18	18	0	0	18	84	114
WPR-B	1 992	2 732	304	317	204	224	355	2 504	3 272
World	4 966	6 360	572	591	862	913	799	6 404	7 865

According to Cohen et al. (2004), ambient PM pollution is estimated to be responsible for about 3% of adult cardiopulmonary disease mortality; about 5% of trachea, bronchus, and lung cancer mortality; and about 1% of mortality in children from acute respiratory infection in urban areas worldwide. This represents approximately 0.80 million premature deaths (*i.e.* 1.2% of global deaths) and 6.4 million years of life lost (*i.e.* 0.5% of total YLL). More specifically, 0.7% of the mortality in high income OECD countries and 1.4 % in non-OECD countries are due to outdoor air pollution (Cohen et al., 2004), suggesting that non-OECD countries are significantly more affected by air pollution than OECD countries.

More recently, Prüss-Üstün and Corvalán (2006) estimated the global burden of disease attributable to environmental conditions. Their results suggest that as much as 24% of global burden of illness and 23% of all deaths are attributable to environmental factors, highlighting differences across regions (17% of all deaths in developed countries vs. 25% in developing countries). However, it should be noted that the authors use a broad definition of environmental conditions, which includes impacts "*of the environment that can be modified by environmental management*" (Prüss-Üstün and Corvalán, 2006 – p 23). Examples of factors included in and excluded from the study are presented in Box 1 below.

[3] The sub-regions which correspond approximately to OECD countries include AMR-A, EUR-A, EUR-B, EUR-C and WPR-A.

Box 1 – Examples of factors included in and excluded from Prüss-Üstün and Corvalán (2006)

Environmental factors included in the study are:
- pollution of air, water, or soil with chemical or biological agents;
- UV and ionizing radiation;
- noise, electromagnetic fields;
- occupational risks;
- built environments, including housing, land use patterns, roads;
- agricultural methods, irrigation schemes;
- man-made climate change, ecosystem change;
- behaviour related to the availability of safe water and sanitation facilities, such as washing hands and contaminating food with unsafe water or unclean hands.

Environmental factors excluded from the study are:
- alcohol and tobacco consumption, drug abuse;
- diet (although it could be argued that food availability influences diet);
- the natural environments of vectors that cannot reasonably be modified (*e.g.* in rivers, lakes, wetlands);
- impregnated bed nets (for this study they are considered to be non-environmental interventions);
- unemployment (provided that it is not related to environmental degradation, occupational disease, etc.);
- natural biological agents, such as pollen in the outdoor environment;
- person-to-person transmission that cannot reasonably be prevented through environmental interventions such as improving housing, introducing sanitary hygiene, or making improvements in the occupational environment.

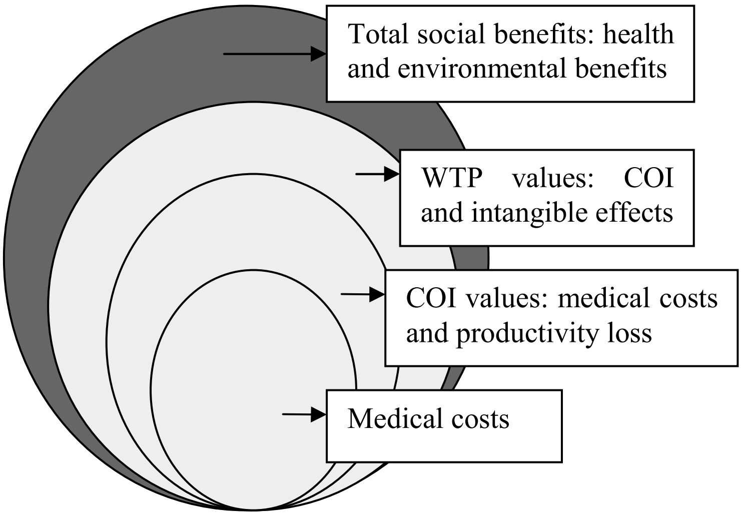
4. Valuation of benefits and costs of environmental policies

4.1 Benefits of policies aiming at reducing air pollution

There are different types of benefits that can be considered in environmental policymaking, *e.g.* environmental, economic, health, social, etc. However, health effects dominate the total value of the benefits from reducing environment-related air pollution (yellow part in Figure 2) and generally represent more than 70% of total benefits.

Health benefits are usually expressed in two forms: either as values of the costs of a disease (*i.e.* costs of illness) or as willingness-to-pay (WTP) values to avoid a given disease or risk. As seen in Figure 2, COI values include medical costs and productivity loss associated with illness, whereas WTP encompass direct and indirect costs of illness and intangible aspects (*e.g.* pain and suffering, time spent in taking care of sick people, impossibility of leisure or domestic activities when sick, etc.) as well. Another difference between COI and WTP is that usually, COI figures are estimated *ex post* while WTP values are generally estimated *ex ante*.

Figure 2 – Benefits of environmental policies



The WTP to improve air quality (*i.e.* reduce air pollution) can be defined as the maximum amount someone is willing to pay for the improvement of air quality while his/her level of welfare has not changed (*i.e.* the individual is just as well off with the improvement as without it). The WTP to reduce mortality risks can be used to derive the value of a change in the risk of death, *i.e.* the "value of a statistical life" (VSL). When compared to COI values, WTP values are considered as the most complete indicator of the value of illness and therefore as the most reliable value to be used in policy-making.

In this section, we propose a review of the literature on COI and WTP studies dealing with selected health problems. Results from these surveys could be theoretically used in environmental policymaking when health effects of environmental policies have to be estimated.

4.1.1 Review of cost of illness studies

Several COI studies have been identified as relevant for our purposes[4]. Therefore, studies are presented according to the type of health impacts they are evaluating.

Asthma- and respiratory disease-related studies

Asthma is a major problem in most OECD countries which are experiencing continuously increasing rates of asthma occurrence. Although the causal relationship between asthma and air pollution has not been scientifically demonstrated, it is reasonable to think that asthma is aggravated (not caused) by air pollution. As such, a number of studies have been undertaken to estimate the cost of asthma associated with air pollution.

In the UK, the Economic Appraisal of the Health Effects of Air Pollution report (Department of Health, 1999) estimated the costs associated with respiratory diseases. They found that the total costs of respiratory diseases (USD 864 million) accounted for around 6% of National Health System hospital costs and around 12% of the National Health System primary care expenditures at that time. The costs associated with respiratory diseases in the UK are presented in Table 10.

[4] National currencies have been converted into 2007 US dollars in using power purchasing parities. Source: OECD, www.oecd.org/std/prices-ppp.

Table 10. Estimated costs associated with respiratory diseases in the UK

	<65 years	65+ years	All ages
Visits (thousands)	247	160	407
Average length of stay (days)	3.9	13.6	7.7
Cost per visit (USD)	**1,075**	**3,752**	**2,120**
Total cost (million USD)	**265**	**599**	**864**

Cho and You (1996) derive social cost of NO_2 associated with respiratory diseases in Korea. Based on cost-of-illness values aggregating medical costs and wage losses, the cost of respiratory diseases associated with NO_2 pollution is USD 357 million.

Later, Jun (1999)[5] addresses the relationship between pollutants (O_3, CO, NO_2, PM_{10} and SO_2) and medical insurance data for asthma in Korea. Medical costs include direct costs of medical treatment and indirect costs such as productivity loss, family costs, traffic costs, and different time costs. The total costs of illness for asthma were estimated at approximately USD 22 million. Most of the costs are attributed to CO (USD 15 million) and O_3 (USD 6 million). PM_{10} pollution contributes only USD 304,300 to medical costs.

Van Ganse et al. (2002) estimate the direct costs of medical resource utilisation for persistent asthma in France. These costs are differentiated over the degree of control. Over a 12-month period, the mean cost was nearly USD 605 for well controlled patients, USD 825 per patient with moderate control and over USD 1,594 per patient with poor control. Large differences were observed in the use of medical resources according to control and severity of asthma.

<u>Several health endpoints</u>

Based upon cost-of-illness values, Stieb et al. (2002) estimate the economic benefits of reducing acute cardio-respiratory morbidity associated with air pollution in Canada. Values of pain and suffering associated with each health endpoint were estimated in a previous stated-preference survey (Johnson *et al.*, 2000). Results are presented in Table 11. Estimates ranged from USD 11 for avoidance of an acute respiratory symptom day to USD 4,238 for avoidance of a cardiac hospital admission. Cardiovascular diseases are the most expensive as they total more than USD 7,700.

[5] Source: Joh (2000).

Table 11. Estimated health costs associated with air pollution in Canada in 2002 (USD)

	Cost of treatment	Lost productivity	Pain and suffering	Total costs
Respiratory hospital admission	2,295	251	888	3,434
Cardiac hospital admission	3,116	218	904	4,238
Respiratory emergency department visit	762	128	781	1,670
Cardiac emergency department visit	2,592	173	833	3,598
Reduced activity day		21	19	39
Asthma symptom day		10	13	23
Acute respiratory symptom day		10	1	11

Two Mexican studies have estimated the cost of illness associated with air pollution for several health endpoints. Costs expressed in USD are presented in Table 12.

Table 12. Estimated cost of illness associated with air pollution in Mexico (USD)

Health endpoint	Studies	
	Cesar et al. (2002)	McKinley et al. (2003)
Chronic bronchitis	218	17,750
Hospital admissions - respiratory	1,870	2,186
Hospital admissions - pneumonia		2,111
Hospital admissions – COPD		17,750
Hospital admissions – asthma		603
Hospital admissions - cardiovascular	5,611	10,890
Emergency room visit - respiratory	91	269
Emergency room visit - asthma		317
Restricted activity days	10	
Asthma attacks	337	
Respiratory symptoms	10	
Chronic cough (children)	190	

Table 12 indicates striking disparities between the two Mexican surveys. Values derived in McKinley et al. (2003) are significantly greater than those derived in Cesar et al. (2002). In particular, the COI attached to chronic bronchitis varies by a factor of 81 between the two surveys. WTP values were also estimated in both surveys (see next section).

For Spain, Monzon and Guerrero (2004) estimated the health costs associated with air pollution in Madrid for the year 1996. Health costs expressed in USD are presented in Table 13. Total costs are estimated over USD 682 million. Mortality costs associated with air pollution account for 89% of the total costs.

Table 13. Health costs of air pollution in Spain in 1996 (USD)

Endpoints	Outcomes	Health costs
Mortality	2696 deaths	607,083,298
Morbidity	6801 admissions	75,418,171

Hospital costs	9 days average stay	12,093,293
Productivity losses	Average: 48 years old	5,716,829
Human suffering	USD 8,462/person	57,608,049
Total		**682,501,469**

The Ontario Medical Association evaluated the cost of illness of air pollution (OMA, 2005). Results are presented in Table 14. In 2005, overall economic losses associated with air pollution exposure are estimated to be over USD 6.4 billion. Mortality represents the most important component of these total costs (82%) while health care costs only represent 6% of total costs.

Table 14. Estimated cost of illness of air pollution in Canada in 2005 (USD)

Endpoints	Economic costs (million USD)
Lost time	308
Health care costs	417
Pain and suffering	442
Premature deaths	5,264
Total	6,430

4.1.2 Review of WTP studies

WTP values for reducing mortality and morbidity risks, for different OECD countries (mainly the US), are presented[6]. WTP values can be interpreted as the potential benefits of environmental policies. Empirical evidence tends to suggest that COI values are lower than WTP values as they do not include intangible costs.

Studies evaluating a reduction in mortality risk

The US EPA (2004) recommends the use of a value of a statistical life (VSL)[7] of USD 5.5 million when estimating the benefits of a policy aiming at reducing mortality risk associated with air pollution.

The EC has commissioned a study on the mortality effects of long-term exposure to air pollution, under the NewExt project (Markandya et al., 2004). The survey estimated WTP values for reducing mortality risk by 5 in 1000, over ten years, in three European countries (France, Italy and the UK)[8]. The results presented in Table 15 are expressed either in terms of VSL or value of a life year (VOLY)[9]. The WTP of USD 1,086 can be interpreted as the benefits of reducing the mortality impacts associated with air pollution.

[6] National currencies have been converted into 2007 US dollars in using power purchasing parities. Source: OECD, www.oecd.org/std/prices-ppp.

[7] The value of a statistical life (VSL) can be defined as the value of a change in the risk of death. The VSL is derived from WTP values and calculated as follows: VSL=WTP/Δp where Δp is a specified reduction of mortality risk (OECD, 2006). Example: if the WTP to reduce the mortality risk by 1/10,000 is USD 200, then the VSL=200/(1/10,000)=2,000,000 or USD 2 million.

[8] Although the Markandya *et al.* study was not specific to air pollution, the conclusions it drew and the WTP estimates it obtained could be used to design environmental policies targeting air pollution.

[9] The VOLY is the value of a life year. It is usually derived from the VSL as follows: VOLY=VSL(A)/(T-A), where VSL(A) is the VSL at age A, T is age at the end of a normal life and A is current age; so that T-A is the remaining life expectancy, or, in other words, the number of remaining life years (OECD, 2006).

Table 15. Estimated WTP to reduce mortality risk and derived VSL and VOLY estimates (USD)

	WTP	VOLY	VSL
Median	526	48,373	1,051,017
Mean	1,086	99,116	2,173,495

Based on the findings from this survey, the EC recommends the use of the following values when valuing mortality risks in environmental policymaking:

- VSL: median: USD 1,077,000, mean: USD 2,199,000[10]
- VOLY: median: USD 57,000; mean: USD 132,000

The survey instrument used in Markandya et al. (2004) had been previously implemented in Canada and in the US[11]. This allows for a comparison of results between Europe and North America. VSL estimates for a 5/1000 risk immediate change are expressed in USD and presented in Table 16.

Table 16. Median and mean VSL estimates in selected countries (USD)

VSL estimates	Europe	Canada	US
Median	1,148,863	491,427	680,523
Mean	2,363,689	906,997	1,496,270

Values derived from the European sample (pooling of three countries results) are greater than those derived from Canada and the US. However, it should be noted that this survey focussed on people of 40 years of age or older – those most affected by air pollution among the adult population. Therefore, the sample is not representative of the whole population and WTP values derived may not reflect the "true" social welfare. In addition, the significant gap between the mean and median values suggests that estimates based upon sub-samples may be particularly biased. Nevertheless, the EC adopts these VSL values in policymaking while the US EPA recommends the use of a VSL (USD 5.5 million) greater than that obtained in these surveys (US EPA, 2004)[12].

Recently, Rabl (2004) undertook a review of COI and WTP studies to provide recommendations on the values to adopt in France for different health impacts. As suggested in EC recommendations (see above), Rabl recommends the use of a VOLY of USD 55,000 in France for both adults and children.

In Italy, Alberini and Chiabai (2004) use a contingent valuation survey to elicit WTP for a reduction in the risk of dying for cardiovascular and respiratory causes, the most important causes of premature mortality associated with heat wave and air pollution. The WTP for the same risk reduction – and hence VSL – declines with age: a 45-year-old's median WTP ranges from USD 200 a year (for the risk reduction of 1 in 10000 a year) to USD 615 (for the risk reduction of 12 in 10000 a year). By contrast, a 65-year-old's annual median WTP ranges respectively from USD 111 to USD 340. The VSL ranges from USD 0.283 million to over USD 6.4 million, depending on the baseline risk/age of the beneficiary, size of the risk reduction, health status, and statistic used to compute the VSL (median or mean WTP).

Based on the same questionnaire that Alberini and Chiabai (2004) applied, a similar CV survey was also conducted in the Czech Republic (Alberini et al., 2006). The WTP for reductions in their own risk of dying for cardiovascular and respiratory causes was elicited. Median WTP lies between USD 243 and USD

[10] Median and mean estimates are provided. Indeed, as VSL distributions are generally skewed, mean estimates may be more robust than the mean estimates.

[11] Results from the Canadian and the US surveys are presented in Alberini et al. (2004).

[12] The VSL applies in Canada is C$1.3 Million, derived from Krupnick et al. (2002).

485. These values allow for the derivation of a mean VSL of USD 3 million and of a median VSL of USD 1.3 million.

Chilton et al. (2004) conducted a CV survey in the UK to estimate the WTP associated with a reduction of air pollution. The originality of this survey is that they express the benefits of risk reduction in terms of extended life expectancy. They ask people to value three scenarios: 1 month, 3 months and 6 months of extra life expectancy. Under reasonable assumptions (1 month scenario), they obtain a WTP of USD 568 per month, which was used to compute a VOLY of USD 44,349 and then a VSL of USD 2 million. These results are currently used in environmental policy-making.

Hammitt and Ibarraban (2002) estimate the WTP of reducing several health effects, including mortality, chronic bronchitis and cold in Mexico City. Estimates were obtained using both contingent valuation and hedonic wage methods. The mean WTP to reduce mortality risk for one year is USD 181, which allows for the derivation of a Mexican VSL of USD 500,000. This value is consistent with estimates of the VSL obtained by transferring US VSL estimates to Mexico.

<u>Studies evaluating a reduction in morbidity risk</u>

1. Chronic bronchitis

Viscusi et al. (1991) estimated the WTP to avoid a 1/100000 risk of chronic bronchitis to be about USD 9 – implying an aggregate WTP of about USD 0.9 million to avoid one case. Mean WTP to avoid chronic bronchitis was USD 883,000.

2. Hospital admissions

Diener et al. (1997) used a conjoint analysis process to assess the WTP for reductions in health effects (including deaths and hospital admissions) due to air pollution in Canada. The average household's WTP was USD 33 per month to reduce the adverse effects of air pollution by 1 excess death and 12 excess hospitalisation admissions per month.

Chestnut et al. (2005) conducted a contingent valuation (CV) survey to estimate the value of preventing respiratory and cardiovascular hospitalisations. Their study allows for the determination of WTP values for preventing hospitalisations. In this survey, two types of WTP estimates are derived: either from an open-ended question or from a close-ended-type question. Open-ended WTP responses allow for the derivation of a mean value of USD 770 per hospitalisation, ranging from USD 400 to USD 950, *i.e.* a mean WTP of USD 260 per day of hospitalisation. The mean WTP for preventing 1-2 days of hospitalisation derived from close-ended questions is about USD 1,900 and similar mean WTP for preventing 5-10 days of hospitalisations is about USD 2,400.

3. Several morbidity risks

Navrud (2001) derives WTP values to prevent coughing, sinus congestion, throat congestion, eye irritation, headache, shortness of breath, acute bronchitis, asthma attacks and combination of morbidity symptoms from a CV survey in Norway. Mean WTP estimates (expressed in USD) to avoid one and 14 extra days of the different health impacts are summarised in Table 17.

Table 17. Estimated mean WTP to reduce selected morbidity risks associated with air pollution in Norway (USD)

Symptoms	WTP to avoid 1 extra day	WTP to avoid 14 extra days
Throat congestion	11	28
Coughing	11	30

Eye itching	15	49
Headache	20	87
Sinus congestion	22	63
Acute bronchitis	23	64
Shortness of breath	30	93
Throat + sinus congestion + coughing	42	126
Asthma attacks (non-asthmatic respondents)	64	191
Asthma attacks (asthmatic respondents)	132	201

Table 17 highlights an issue associated with the choice of the survey sample: asthmatic respondents value significantly more an asthma attack than non-asthmatics do. Indeed, affected people are more familiar with the good being valued (avoid of an asthma attack) and therefore provide a more reliable value. Table 17 also underlines a problem associated with many contingent valuation surveys: scope insensitivity, *i.e.* the WTP to avoid 14 days of a specific symptom is not equal to 14 times the WTP to avoid one day of this symptom.

Vassanadunrongdee *et al.* (2004) proposed a meta-analysis of existing CV studies estimating reductions in morbidity risks associated with air pollution. Results of this meta-analysis are reported in Table 18. The results suggest a high variation not only across health effects but also across studies. Differences in the values between studies can be related to the elicitation method applied, and to a lesser extent to national characteristics. Although most of the studies used in the meta-analysis come from the US, one considers the EU as a whole and two have been undertaken in individual European countries (Portugal and Norway). In addition, no single study provided estimates for the whole set of health endpoints for which Vassanadunrongdee *et al.* provided values. This may explain the differences between estimates of health effects (they have not all been estimated in a single study and in a consistent way).

Table 18. Estimated WTP values for 1 day avoidance of various illnesses (USD)

Health effects	Vassanadunrongdee et al. (2004)	Previous meta-analyses	David (1999) Portugal	Dickie et al. (1997) US	Loehman et al. (1979) US	Navrud (1998) Norway	Ready et al. (2001) EU	Rowe & Chestnut (85) US	Tolley et al. (1986) US
Mild cough	31	25	70	15	12	15			33
Severe cough	42	45			34		43		
Mild headache	29	23		25	20				53
Severe headache	39	40			47	26			
Mild shortness of breath	31	25		9	35				
Severe shortness of breath	58	77			64	40			
Eyes irritation	28	20	86			20	58		37
Severe asthma attack	58	77				85		60	
Throat irritation	21			22		15			39

Rabl (2004) provides recommended values of unit costs that should be used in France for different morbidity risks. They are reported in Table 19. Total costs include the medical cost of illness (COI) but also the willingness-to-pay (WTP) related to avoiding the suffering and inconvenience of disease.

Table 19. Estimated unit costs of selected morbidity risks

Health endpoint	Cost of illness (USD)	WTP to avoid suffering (USD)	Total (range) (USD)
Cancer, fatal	54,970	2 million	2 million (0.55 million – 3.3 million)
Cancer, non-fatal	54,970	0.55 million	0.55 million
Chronic bronchitis			186,896
Minor restricted activity day		45	44
Restricted activity day	93	54	143
Workday lost	93	54	143
Emergency room visit	88 + 467	266	825
Asthma attacks, per case	202	34	242
Asthma, per year	1,979	220	2,199
Respiratory symptoms simple bronchitis	37	34	71
severe bronchitis	248	220	440 (330 – 550)
Laryngitis/pharyngitis	33	34	66
Sinusitis	112	66	198
Respiratory hospital admissions, per day	385 + 93		550 (330 – 660)
Respiratory hospital admissions, per case	2,748 + 654		3,408 (2,199 – 4,947)
Cardiovascular hospital admissions, per case			5,387 (3,848 – 6,596)

Source: Rabl (2004).

Table 19 highlights the significance of cancers and chronic bronchitis on the total costs. Acute impacts, such as hospital admissions, contribute relatively little to the total costs. The Table also highlights the need to correctly account for intangible effects.

The study of Ready *et al.* (2004) provides a cross-country comparison of WTP for avoiding several health endpoints. They estimate and compare the benefits of a specific improvement in health as measured in simultaneous contingent valuation surveys conducted in 5 different European countries: Portugal, Spain, England, Norway and the Netherlands. WTP estimates converted to USD obtained from this survey are presented in Table 20.

Table 20. Estimated WTP to avoid selected morbidity endpoints in five European countries (USD)

	Pooled	Netherlands	Norway	Portugal	Spain	England
Hospitalisation	467	432	459	459	650	250
3 bed days	148	108	181	134	172	127
Cough	41	43	55	43	59	31
Eyes irritation	53	61	47	107	81	21
Stomach pain	53	0	0	93	0	40

For Mexico, Cesar et al. (2002) estimates the WTP for several morbidity impacts. These estimates are obtained via a benefit transfer method. The original values come from US EPA (1999) and ExternE (1999). Table 21 presents the values (in USD) derived for Mexico, assuming an income elasticity of 1.

Table 21. Estimated WTP to avoid selected morbidity risks in Mexico (USD)

Endpoints	WTP
Hospital admission	
Respiratory	153
Cardiovascular	153
Congestive heart failure (elderly)	153
Emergency room visits	
Respiratory	79
Restricted activity days	21
Minor restricted activity days	21
Asthma attacks	15
Cough without phlegm (children)	21
Cough with phlegm (children)	21
Some respiratory symptoms (children)	21
Chronic bronchitis (new cases)	118,074
Chronic cough (prevalence, children)	116

In addition to the COI values provided in Table 12 (see above), McKinley et al. (2005) present WTP values for avoiding selected morbidity endpoints associated with air pollution in Mexico. Some of them are directly comparable to the findings from Cesar et al. (2002), as presented in Table 22.

Table 22. Comparison of estimated WTP and VSL values derived for Mexico (USD)

Endpoints	Cesar et al. (2002)	McKinley et al. (2003)
VSL		506,000
Chronic bronchitis	118,074	28,000
Hospital admission - Respiratory	153	330
Hospital admission - cardiovascular	153	330
Emergency room visits - respiratory	79	170
Emergency room visits - asthma	79	170
Minor restricted activity days	21	20

As with the COI estimates there are striking differences between the two Mexican studies. The McKinley *et al.* study proposes much larger values than the Cesar *et al*. study, except for a case of chronic bronchitis which is valued 4 times more in Cesar *et al.* (2002) than in McKinley *et al.* (2005).

Ibarraban et al. (2005) also report WTP estimates of the value of preventing several environment-related health effects in Mexico City. The mean WTP to prevent a minor illness (cold) is USD 28. The WTP to reduce the risk of getting chronic bronchitis amounts USD 106, which can be used to derive the value of a statistical case of chronic bronchitis of USD 30.

Studies evaluating a reduction of air pollution

In Sweden, several stated preferences surveys have been conducted in order to derive WTP values for improved air quality. Results are summarised in Table 23.

Table 23. Estimated WTP values to improve air quality in Sweden (USD)

Study	Good being valued	WTP for a 50% reduction	Method
Strand and Taraldset (1991)	Air pollution	USD 196-402/year and household	Open-ended CV
Transek (1993)	Traffic-related air pollution	Health damages: USD 190/year and person Damages to nature: USD 162/year and person Damages on buildings: USD 83/year and person	Experimental ranking
Saelensminde and Hammer (1994)	Air pollution	USD 500-1011/ year and household	Experimental choice
Halvorsen (1996)	Traffic-related air pollution	USD 136/year and person	Open-ended CV
Carlsson and Johansson-Stenman (2000)	Air pollution	USD 217/year and person	Open-ended CV

Source: adapted from Carlsson and Johansson-Stenman (2000).

D.A. Parry Dziegielewska and R. Mendelsohn (2005) estimated the value of improved air quality in Poland. To this end, they propose a scenario that allows for the valuation of the total effects of air pollution. Each person is asked to consider individually changes in: mortality, bronchitis, asthma, minor health effects, visibility, material and historical damages (*i.e.* damages to cultural heritage) and damages to ecosystems as well. Median WTP estimates (in USD) are presented in Table 24, for two scenarios: an improvement in air quality of 25% and a quality improvement of 50%.

Table 24. Estimated WTP estimates to improve air quality in Poland (USD)

Damages	25% improvement	50% improvement
Mortality	29	41
Bronchitis	9	10
Asthma	9	9
Minor health effects	4	4
Visibility	4	4
Materials	0	2
Historical	4	3
Ecosystems	7	10
Total	**67**	**84**

The table clearly highlights the importance of the mortality component (more than 40% of total value), and health in general (more than 75% of total value).

OECD non-member countries

Similar surveys have been conducted in non-member countries. Among those, three are of particular relevance. The first one was implemented by Alberini and Krupnick (2000) and provided WTP estimates of the benefits of different scenarios aiming at improving air quality in Taiwan (see Table 25).

Table 25. Estimated WTP to improve air quality in Taiwan (USD)

PM_{10} concentration ($\mu g/m^3$)	Total COI (USD)	WTP (USD)
100	628,074	1,038,187
150	696,867	1,234,551
350	1,048,775	2,374,087

The estimates increase with increased PM_{10} concentrations because as pollution worsens, people are more affected and develop more symptoms. Moreover, these results are consistent with economic theory, which predicts that COI measures are inferior to corresponding WTP values.

Another relevant survey was conducted by Liu et al. (2000) in Taiwan. They implemented a contingent valuation study in Taiwan to estimate a mother's WTP for preventing her from getting another case of the cold she typically gets and her WTP for preventing her child from getting another case of the cold the child typically gets. The mother's WTP to prevent her child from suffering a cold (USD 57) is approximately 50% greater than her WTP to prevent herself from getting a cold of comparable duration and severity (USD 37). This can suggest that mothers value their child's health more than their own.

The last example relates to a study implemented in China. Hammitt and Zhou (2005) conducted a CV survey to elicit the economic value of preventing adverse health effects related to air pollution. Values are estimated for three health endpoints: cold, chronic bronchitis, and fatality. The median WTP to prevent an episode of cold ranges between USD 3 and USD 6, the WTP to prevent a statistical case of chronic bronchitis ranges between USD 500 and USD 1,000, and the value per statistical life ranges between USD 4,000 and USD 17,000. These estimates are between about 10 and 1,000 times smaller than estimates for the US and Taiwan using official exchange rates.

4.2 Comparison of costs and benefits of environmental policies

In order to assess the efficiency of environmental policies, it is useful to carry out cost-benefit analyses as they provide values that allow for a direct comparison of the likely costs of implementation and benefits (in general, health and environmental benefits) associated with a given policy. As such, a CBA allows to know whether the policy is economically efficient (*i.e.* whether the social benefits outweigh the social costs). Examples of cost-benefit analyses undertaken to assess the potential efficiency of environmental policy proposals and of *ex post* policy evaluations undertaken to assess the efficiency of past or current policies are presented in this section to answer the question: are environmental policies social welfare improving?

4.2.1 Assessment of costs and benefits from ex ante policy evaluation

A cost-benefit analysis (CBA) has been recently made by Massé (2005) in France in order to assess the effectiveness of putting particle filters on personal and public vehicles. This study shows that implementation of particles filters to all types of vehicles (personal and public) would lead to a decrease of PM_{10} concentrations by almost 20% (mean value) and of $PM_{2.5}$ concentrations by 31% (mean value). Health benefits associated with these reductions would be rather substantial and significantly greater than implementation costs, as follows:

- Implementation of filters on trucks and buses: 120,000 life years saved per year and a discounted net benefit[13] of USD 24.7 billion; and,
- Implementation of filters on individual vehicles: 200,000 life years saved and a discounted net benefit of USD 10 billion.

[13] The author uses a 4% discount rate and a VOLY of USD 54,970, as recommended in national guidelines.

A CBA of the EC CAFE programme has been undertaken (AEA Environment Technology, 2005). This report assesses the benefits of the implementation of current policies over the 2000-2020 period. Several types of impacts were considered, including impacts on health, on materials (buildings), on crops and on ecosystems (freshwater and terrestrial, including forests). These impacts were quantified and monetised as far as possible. Based upon the NewExt study results (Alberini *et al*., 2004), the health effects have been expressed in monetary terms. Different scenarios are considered: low reduction, medium reduction, high reduction, current strategy and the "Maximum Technically Feasible Reduction" (MTFR) scenario[14].

Different reduction scenarios were proposed and their associated expected costs and benefits for 2020 were computed. As benefits can be derived from either mean or median VSL, a range of benefits is provided instead of a central estimate. The figures are presented in Table 26.

Table 26. CBA of CAFE programme (USD)

Policy scenarios	Health benefits (billion USD)	Programme Costs (billion USD)	Benefit to cost ratio
Strategy – 2020	46-148	8	6-19
Low reduction scenario – 2020	41-132	6	6-20
Medium reduction scenario – 2020	49-161	12	4-13
High reduction scenario – 2020	54-176	16	3-11
MTFR scenario - 2020	62-199	44	1.4-4.5

Source: adapted from AEA Technology Environment (2005).

Results in Table 26 suggest that quantifiable expected health gains of the CAFE programme range from USD 41 billion to USD 199 billion in 2020. The benefits significantly outweigh the costs in all the scenarios considered. However, it should be noted that this CBA excludes benefits from effects on crops, materials and ecosystems as they were not included in the monetary framework. This then suggests even greater net social benefits.

In Canada, a cost-benefit analysis was conducted in order to determine the most efficient air-quality options. This CBA was undertaken in the context of Canada Wide Standards (CWS) for particulate matter (PM) and ozone. The Air Quality Valuation Model (AQVM) was used to estimate the health and environmental benefits associated with reductions in ambient levels of PM and ozone. The AQVM adopt a VSL of USD 3.4 million. Results from the CBA showed that the number of avoided death was rather substantial, (from 326 to 3,563 according to different scenarios) and so were the monetised benefits. Table 27 reports benefit and cost values as well as benefit to cost ratios for the various policy options.

[14] MTFR illustrates "maximal technical feasible reductions" and does not include structural abatement measures such as fuel switch or energy efficiency.

Table 27. Anticipated costs and benefits of the Canadian Wide Standards for PM and Ozone (USD)

Target pollutant level	Avoided mortality (death / year)	Benefit of avoided mortality (million USD / year)	Estimated cost (million USD / year)	Benefit to cost ratio
Pm10 / PM2.5 (µg/m3)				
70/35	1,021	3443	140	24.6
60/30	1,639	5527	510	10.8
50/25	2,790	9408	1316	7.1
Ozone (ppb)				
70	167	563	650	0.9
65	203	684	1539	0.4
60	239	806	5348	0.2
CWS: PM10/PM2.5/Ozone				
60/30/65	**1,842**	**6211**	**2049**	**3.0**

Source: Pandey et al. (2003).

Table 27 clearly shows that societal benefits of any policy option are much larger than corresponding social costs. Reductions in PM levels are highly beneficial while reductions in ozone exhibit costs larger than benefits. However, the overall CWS for both PM and Ozone pass the cost-benefit test, with a benefit-to-cost ratio of 3.

Air pollution is a major problem in Mexico. A cost-benefit analysis was undertaken in Mexico City in order to determine the efficiency of an ultra-low sulphur fuels policy (Blumberg, 2004). Benefits only consider health consequences and costs were only related to refining fuels. The results of the CBA presented in the table below are also derived for the entire nation.

Table 28. CBA of ultra-low sulphur fuel policy in Mexico (USD)

	Costs (million USD)		Benefits (million USD)	
Range	Low	High	Low	High
Mexico City	120	250	2,456	4,874
Mexico (nationwide)	648	1,354	9,665	12,083

The results from this CBA suggest that substantial health benefits are associated with a reduction in sulphur content of fuels. In addition, this policy intervention is very efficient with a benefit-to-cost ratio between 10 and 19 for Mexico City and between 7 and 9 for Mexico as a whole, generating net benefits of at least $8 billion at the nationwide level (low range benefits minus high range costs - Mexico).

Another CBA was carried out more recently in Mexico and deals with retrofitting of diesel vehicles in order to reduce harmful diesel-related PM emissions (Stevens et al., 2005). The authors estimate the expected benefits and costs of a proposed policy programme to retrofit diesel vehicles (for 2010). Different emissions control technologies are proposed to reduce PM emissions, including diesel particle filters (DPF) and diesel oxidation catalysts (DOC). More precisely, two types of DPF are considered: catalysed DPF and active regeneration filters. Three types of vehicles are analysed: urban transportation buses, delivery trucks, and long-haul tractor trailers and they are differentiated according to their age (old vs. new vehicles). The median costs and benefits (expressed in million USD) of the different policy options in 2010 are presented in Table 29 below.

Table 29. CBA of alternatives to reduce diesel-related PM emissions (USD)

	Old vehicles (before 1994)			New vehicles (1994 and after)		
	Benefits	Costs	**Net benefits**	Benefits	Costs	**Net benefits**
Catalysed DPF						
Bus				2	0.3	**1.7**
Truck				1.4	0.2	**1.1**
Tractor trailer				0.8	0.4	**0.4**
Active regeneration DPF						
Bus	8.9	0.8	**8.1**	2	0.6	**1.4**
Truck	3	0.6	**2.5**	1.4	0.4	**1**
Tractor trailer	2.9	0.9	**1.9**	0.8	0.7	**0.1**
Oxidation catalyst						
Bus	2.6	0.1	**2.6**	0.7	0.1	**0.7**
Truck	1	0.1	**0.9**	0.5	0.1	**0.4**
Tractor trailer	0.8	0.1	**0.7**	0.2	0.1	**0.1**

The different policy alternatives are expected to provide positive net benefits to society, although retrofit with a catalysed filter would be the most efficient option. In particular, Table 29 suggests that retrofitting of old diesel trucks would be significantly cost-efficient (benefit-to-cost ratio of 5). Within the particle filters technologies, catalysed filters are likely to provide greater net benefits than active regeneration filters.

As required in the US Clean Air Act (CAA), an evaluation of the CAA has been performed by the US EPA in 1999 (US EPA, 1999). It was undertaken in order to assess the social costs and benefits. Two different scenarios were considered: no additional control requirements after CAA (2000) and further control requirement (2010). The analysis focused on six major pollutants: PM_{10}, $PM_{2.5}$, NO_x, SO_2, CO and VOC. The cost and benefit estimates are presented in Table 30.

Table 30. Estimated costs and benefits of the Clean Air Act (USD)

	Central annual estimates (million USD)	
	2000	2010
Costs	$19,000	$27,000
Benefits	$71,000	$110,000
Net benefits	**$52,000**	**$83,000**
Benefit to cost ratio	4/1	4/1

The table clearly indicates substantial net social benefits from the CAA. Monetised benefits exceed the direct cost by four to one. The CAA is an efficient policy intervention, with four dollars of benefits for every dollar of cost.

4.2.2 Assessment of costs and benefits from ex post policy evaluation

In Japan, Voorhees et al. (2000) carried out an *ex post* CBA of NO_2 control policies in Tokyo beginning in 1973. Examples of NO_x control interventions include fuel conversion, low NO_x burners, and various catalytic reduction processes. The annual benefits estimated included medical expenses and lost work time, while direct costs were calculated as annualized capital expenditures and 1 year's operating costs. On the benefit side, the authors only considered the health effects, and more specifically selected respiratory illnesses related to NO_2 pollution (phlegm and sputum in adults, and lower respiratory illness in children). Their results are presented in Table 31.

Table 31. *Ex post* evaluation of NO_2 control interventions in Japan (USD)

	Mean estimates (USD)
Benefits	
Avoided medical costs in adults	6,080 million
Avoided medical costs in children	775 million
Avoided costs of lost wages in workers	6,330 million
Avoided costs of lost wages in mothers	833 million
Total benefits	**14,018 million**
Costs	
Total costs	**2,330 million**
Benefit to cost ratio	**6**

The results from the CBA show that NO_2 control policies that were undertaken in Tokyo were quite effective, with approximately six dollars of benefits for every dollar of cost.

An *ex post* evaluation of the UK Air Strategy was carried out in 2004 (AEA Environment Technology, 2004). This study considers 10 years of air quality policies in the UK, with a particular focus on two sectors: road transport and electricity generation. This *ex ante* assessment allows for the determination of *ex ante* and *ex post* costs as well as *ex post* benefits. Their respective estimates, expressed in million USD, are presented in Table 32.

Table 32. Estimated Costs (ex ante and ex post) and benefits (ex post) of the UK Air Strategy (USD)

Evaluation period: 1990-2001 (million £)			
	Ex ante costs	*Ex post* costs	*Ex post* benefits
Road transport	24,567-34,781	3,050-6,100	4,485-28,015
Electricity	9,150-45,751	3,050	16,484-77,180

Table 32 clearly indicates that *ex ante* estimates of costs are much larger than *ex post* estimates of costs. In addition, the UK Air Quality Strategy seems to be quite efficient as benefits always outweigh the (*ex post*) costs. Benefit-to-cost ratios vary between 1.5 and 5 for road transport policies, and between 5 and 25 for electricity policies.

4.2.3 Assessment of the economic burden of environmental health issues

The economic burden of environmental health is also quite significant in both OECD and non-OECD countries. Two recent economic studies provided estimates of the total health costs of selected environmental risk factors.

For example, Muller and Mendelsohn (2007) estimated the gross annual damages in the US associated with six different air pollutants: ammonia, nitrogen dioxide, PM_{10}, $PM_{2.5}$, sulphur dioxide and volatile organic compounds. Depending on the precise approach used for modelling the human health effects, the study estimated the gross annual damages to range between USD 71 billion (0.7% of GDP) and USD 277 billion (2.8% of GDP) per year. A plausible scenario led to an annual global estimate of USD 74.3 billion (0.7% of GDP), 94% of which are related to the health impacts (USD 53 billion for mortality damages and USD 17 billion for damages due to illnesses).

Similarly, the World Bank (2007) estimated the health costs associated with air pollution in China based on a WTP approach. Total air pollution damages to health represent 3.8% of China GDP (approximately USD 69 billion). The costs associated with mortality are estimated to be approximately USD 52 billion, while the costs associated with morbidity raise approximately USD 17 billion. This study also highlights the importance of premature mortality in the total monetary health costs of air pollution (75% in this study).

These analyses draw attention to the economic importance of the health costs of air pollution, representing a significant share of the GDP.

5. Conclusions

The increasing interest on the linkages between environment and human health has resulted in a growing number of epidemiological and economic studies. In particular, an extensive literature focuses on the health impacts of air pollution. This report provides examples of economic studies with the objective of estimating the benefits of implementing environmental policies which could improve air quality, and therefore reduce adverse impacts on health. The examination of these studies suggests that mortality costs are the most significant component of total health costs (often over 70%) while healthcare costs (mainly hospital admissions) are relatively less important. The comparison of COI and WTP studies highlights the importance of correctly accounting for intangible effects which therefore recommends the use of WTP as far as possible.

Although cost-benefit analysis is not a tool commonly applied in environmental policymaking in all OECD countries (see Scapecchi, 2007), relevant studies have been presented. Although the examples provided do not constitute an exhaustive list of studies (epidemiological and economic) on the health costs of air pollution, their results suggest that prevention of health impacts associated with air pollution (and more generally with environmental degradation) can be substantially beneficial.

Examples of CBA show a wide variation between interventions in terms of benefit to cost ratio (BCR). Many lessons can be derived from this variation. First, the less stringent policies are rather effective with a BCR of 6 to 20 (see for example "low reduction" scenario of the CAFE strategy). Second, "simple" policies are sometimes the most efficient, as reflected in fuel quality policies that present a BCR of 10 to 19 (see the ultra-low sulphur fuels in Mexico). Third, policies introduced recently benefit from the experience of countries which introduced similar policies few years before. Fourth, policies targeting several pollutants at the same time are more efficient than single pollutant-policies, meaning that there are economies of scope in abatement policies. Fifth, benefits vary across countries, mainly because of GDP differences between countries. Finally, a comparison of *ex ante* and *ex post* evaluations suggests that costs are often overestimated, while benefits are underestimated because of information failures, mainly as a result of strategic behaviour from involved industries (see AEA Technology Environment, 2005).

In summary, policies which result in improved air quality are generally cost-efficient, even when only health benefits are considered. This is particularly true for environmental policies aiming at reducing PM emissions, probably due to the relatively strong link that exists between PM exposure and premature mortality. Benefits of air quality improving policies therefore outweigh the costs, even though only health impacts are considered in most of the policies reported (except the CBA of the Clean Air Act which considers all social benefits). This is due in part to the fact that the health benefits of environmental interventions represent approximately 70-80% of total benefits, although there is much variation. Since the examples of CBA provided only consider the health benefits of a specific intervention, they underestimate the total social benefits which also include benefits to the environment.

Environmental policies should therefore continue to focus on reducing emissions and concentrations of air (and other environment-related) pollutants that cause the strongest adverse health effects, such as PM_{10} and O_3. However, it should be noted that environmental policies have a substantial effect on air pollution, but they are by no means the only contributor to reductions in air pollution levels. Evaluating the benefits of a given policy depends to a great extent on the credibility of the baseline assumptions made about certain key factors (rate of growth of vehicle stock, technological change, *etc*.).

If inadequate decisions are taken (*e.g.* not grounded on scientific basis), the costs due to environmental pollution would likely become greater in the years ahead. Increased investment is required in environmental monitoring and surveillance, in epidemiologic studies and in prevention-oriented research and action. Most importantly, environmental policies should continue to focus on reducing emissions and concentrations of pollutants that have the most important adverse effects on human health.

REFERENCES

Abt Associates (2000), "The Particulate-Related Health Benefits of Reducing Power Plant Emissions", Report Prepared for Clean Air Task Force Boston, Massachusetts.

AEA Technology Environment (2004), "An Evaluation of the Air Quality Strategy", Final Report to DEFRA, November 2004.

AEA Technology Environment (2005), "CAFE CBA: Baseline Analysis 2000 to 2020", Final Report to the European Commission DG Environment, April 2005.

Alberini A. and A. Chiabai (2005), "Urban Environmental Health and Sensitive Populations: How Much are the Italians Willing to Pay to Reduce their Risks?", Working Paper 105.2005, Fondazione Eni Enrico Mattei.

Alberini A. and A. Krupnick (2000), "Cost-of-illness and Willingness-to-pay Estimates of the Benefits of Improved Air Quality: Evidence from Taiwan", *Land Economics*, Vol. 76, No. 1, pp. 37-53.

Alberini, A., M. Ščasný, M. Braun Kohlová and J. Melichar (2006), "The Value of Statistical Life in the Czech Republic: Evidence from a Contingent Valuation Study", In B. Menne, and K. L. Ebi (Eds.), *Climate Change and Adaptation Strategies for Human Health*, Darmstadt: Steinkopff Verlag, pp. 373- 393.

Alberini, A., Krupnick, A., Cropper, M., Simon, N., and Cook, J. (2001), "The Willingness to Pay for Mortality Risk Reductions: A Comparison of the United States and Canada", Working Paper 92-2001, Fondazione Eni Enrico Mattei.

Alberini, A., M. Cropper, A. Krupnick, and N. Simon (2004), "Does the Value of a Statistical Life Vary with Age and Health Status? Evidence from the US and Canada", *Journal of Environmental Economics and Management*, Vol. 48, pp. 769-792.

Blumberg, K. (2004), "Benefit-cost Analysis of ultralow sulphur fuels for Mexico", mimeo.

Carlsson F. and O. Johansson-Stenman (2000), "Willingness to Pay for Improved Air Quality in Sweden", *Applied Economics*, Vol. 32, pp. 661-669.

Cesar H. et al (2002), "Improving Air Quality in Metropolitan Mexico City – An Economic Valuation", Policy Research Working Paper No. 2785, The World Bank.

Chestnut L.G., M.A. Thayer, J.K. Lazo, and S.K. van den Eeden. (2005), "The Economic Value of Preventing Respiratory and Cardiovascular Hospitalizations", *Contemporary Economic Policy*, Vol. 24, No. 1, pp 127-143.

Chilton S., J. Covey, M. Jones-Lee, G. Loomes and H. Metcalf (2004) "Valuation of Health Benefits Associated with Reductions in Air Pollution", Final Report to DEFRA, May 2004.

Cho, J. and W. You (1996), "Social costs of air pollution from CO2 emissions", *Korea Journal of Resource Economics*, Vol.6, No. 1, pp. 111-128.

Cohen A.J., H.R. Anderson, B. Ostro, K. Dev Pandey, M. Krzyzanowski, N. Künzli, K. Gutschmidt, A. Pope, I. Romieu, J.M. Samet and K. Smith (2005), "The Global Burden of Disease Due to Outdoor Air Pollution", *Journal of Toxicology and Environmental Health*, Part A, Vol. 68, pp.1–7.

Cohen, A.J., H. R. Anderson, B. Ostro, K. Dev Pandey, M. Krzyzanowski, N. Künzli, K. Gutschmidt, C.A. Pope III, I. Romieu, J. M. Samet and K. R. Smith (2004), "Urban Air Pollution", In M. Ezzati et al. (Eds.), *Comparative quantification of health risks: global and regional burden of disease attributable to selected major risks factors,* World Health Organization, p. 1353-1433.

Department of Health – Ad-hoc Group on the Economic Appraisal of the Health Effects of Air Pollution (1999), *Economic Appraisal of the Health Effects of Air Pollution*, The Stationery Office, London, UK.

Diener A.A., R.A. Muller and A.L. Robb (1997), "Willingness-to-Pay for Improved Air Quality in Hamilton-Wentworth: A Choice Experiment", Working Paper No 97-08, Department of Economics, McMaster University, Hamilton, Ontario, Canada

EEA (2002), *Children's Health and Environment: A Review of Evidence*, A Joint Report from the European Environment Agency and the WHO Regional Office for Europe, Environmental Issue Report No. 29, Luxembourg.

ExternE (1999), "ExternE - Externalities of Energy", Vol. Methodology 1998 update, (Ed. M. Holland, J. Berry and D. Foster), European Commission DGXII, Science Research and Development, EUR 19083, ISBN 92-828-7782-5, Luxembourg.

Ezzati, M. et al. (Eds.) (2004), *Comparative Quantitative of Health Risks - Global and regional burden of disease attributable to selected major risk factors*, World Health Organization.

Fisher G., K. Rolfe, T. Kjellstrom et al. (2002), *Health Effects Due to Motor Vehicle Air Pollution in New Zealand,* Report to the Ministry of Transport.

Ha E.-H., J.-T. Lee, H. Kim, Y.-C. Hong, B.-E. Lee, H.-S. Park and D.C. Christiani (2003), "Infant Susceptibility of Mortality to Air Pollution in Seoul, South Korea", *Pediatrics*, Vol. 111, pp. 284-290.

Halvorsen B. (1996), "Ordering Effects in Contingent Valuation Surveys: Willingness to Pay for Reduced Health Damage from Air Pollution", *Environmental and Resource Economics*, Vol. 8, pp. 485-499.

Hammitt J.K. and M.E. Ibarraràn (2002), "Estimating the Economic Value of Reducing Health Risks by Improving Air Quality in Mexico City", Newsletter on Integrated Program on Air Pollution, Vol. 2, Fall 2002, Massachusetts Institute of Technology.

Hammitt, J.K. and Y. Zhou (2004) "The Economic Value of Air-Pollution-Related Health Risks in China: A Contingent Valuation Study", Working Paper.

Hausman, J.A., (Eds.) (1993), Contingent Valuation: A Critical Assessment, Contribution to Economic Analysis, Vol. 220, North Holland, Amsterdam, 1993.

Hong Y.C., J.H. Leem and E.H. Ha (1999), “Air pollution and daily mortality in Inchon, Korea”, *Journal of Korean Medical Sciences*, Vol. 14, pp. 239-244.

Joh S. (2000), “Studies on Health Benefit Estimation of Air Pollution in Korea”, Paper prepared for Expert Workshop on Assessing the Ancillary Benefits and Costs of Greenhouse Gas Mitigation Strategies, 27-29 March 2000, Washington, DC.

Johnson F.R., M.R. Banzhaf and W.H. Desvousges (2000), “Willingness to Pay for Improved Respiratory and Cardiovascular Health: a Multiple-format, Stated-preference Approach”, *Health Economics*, Vol. 9, No. 4, pp. 295-317.

Judek S., B. Jessiman, D. Stieb and R. Vet (2004), “Estimated Number of Excess Deaths in Canada Due To Air Pollution”, Working Paper.

Jun, S.I. (1999), “Impact of Air Pollution on Health and its Costs of Illness in Seoul”, Doctoral dissertation, Department of Public Health, Seoul National University, 1999.

Krzyzanowski M., B. Kuna-Dibbert and J. Schneider (2005), *Health Effects of Transport-related Air Pollution*, WHO publication, Copenhagen.

Krupnick, A., Alberini, A., Cropper, M., Simon, N., O’Brien, B., Goeree, R, and Heintzelman, M., (2002), “Age, Health and the Willingness to Pay for Mortality Risk Reductions: a Contingent Valuation Survey of Ontario Residents”, *Journal of Risk and Uncertainty*, Vol. 24, No. 2, pp. 161-186.

Landrigan, P., C. Schechter, J. Lipton, M. Fahs and J. Schwartz. 2002. Environmental Pollutants and Disease in American Children: Estimates of Morbidity, Mortality, and Costs for Lead Poisoning, Asthma, Cancer, and Developmental Disabilities. *Environmental Health Perspectives,* Vol. 110, No. 7, pp. 721–728.

Liu, J.T, Hammitt, J.K., Wang, J.D. and Liu, J.L. (2000), “Mothers Willingness To Pay For Her Own And Her Child’s Health: A Contingent Valuation Study in Taiwan”, *Health Economics,* Vol. 9, pp. 319-326.

Markandya, A., A. Hunt, A. Alberini and R.A. Ortiz (2004), “The Willingness to Pay for Mortality Risk Reductions: An EU 3-Country Survey”, Report to EC DG Research, Brussels.

Massé E. (2005), “Analyse Économique de la Rentabilité des Filtres à Particules sur les Véhicules Diesels Neufs”, *Économie et Prévision*, n° 167 2005/1, pp.16-23.

McKinley, G., *et al.* (2003), *Final Report of the Mexico City Co-Benefits Project*, Instituto Nacional de Ecología and the US Environmental Protection Agency Integrated Strategies Program, August 2003.

Monzon A. and M.-J. Guerrero (2004), “Valuation of Social and Health Effects of Transport-related Air Pollution in Madrid (Spain)”, *Science of the Total Environment*, Vol. 334– 335, pp. 427–434.

Navrud S. (2001), “Valuing Health Impacts from Air Pollution in Europe – New Empirical Evidence on Morbidity”, *Environmental and Resource Economics*, Vol. 20, pp. 305-329.

OECD (2004), *OECD Key Environmental Indicators*, OECD Publication, Paris.

OECD (2005), *OECD Environmental Data – Compendium 2005,* OECD Publication, Paris.

OECD (2006), *Cost-benefit Analysis and the Environment – Recent Developments*, OECD Publication, Paris.

Ontario Medical Association (OMA) (2005), *The Illness Costs of Air Pollution: 2005–2006 Health and Economic Damage Estimates,* Toronto.

Pandey, M.P. and J.S. Nathwani (2003), "Canada Wide Standard for Particulate Matter and Ozone: Cost-Benefit Analysis Using a Life Quality Index", *Risk Analysis*, Vol. 23, No. 1, pp 55-67.

Parry Dziegielewska D.A. and R. Mendelsohn (2005), "Valuing Air Quality in Poland", *Environmental and Resource Economics*, Vol. 30, pp. 131-163.

Prüss-Ustün, A. and C. Corvalán (2006) *Preventing disease through Healthy Environments – Towards an Estimate of the Environmental Burden of Disease*, WHO Publication, Geneva.

Rabl A. (2004), "Valuation of Health End Points for Children and for Adults", Working Paper.

Ready R., S. Navrud, B. Day, R. Dubourg, F. Machado, S. Mourato, F. Spanninks and M.X. Vazquez Rodriquez (2004), "Benefit Transfer in Europe: Are Values Consistent across Countries?", Working Paper.

Scapecchi, P. (2007), "Use of Evaluation Tools in Environmental Policy-making, with a Focus on Health Implications for Children", Internal Document.

Schwela, D. and Gopalan, H. (2002), "Ambient Air Pollution and Emerging Issues in Megacities" in Haq, G., Han, W. and Kim, C. (Eds.), *Urban Air Pollution Management and Practice in Major and Mega Cities of Asia. Korea Environment Institute*, Korea.

Stevens G., A. Wilson and J.K. Hammitt (2005), "A Benefit-Cost Analysis of Retrofitting Diesel Vehicles with Particulate Filters in the Mexico City Metropolitan Area", *Risk Analysis*, Vol. 25, No. 4, pp. 883-899.

Stieb, D., Civita, P.D., Johnson, F.R., Manary, M.P., Anis, A.H., Beveridge, R.C., and Judek, S., (2002), "Economic Evaluation of the Benefits of Reducing Acute Cardiorespiratory Morbidity associated with Air Pollution", *Environmental Health: A Global Access Science Source 2002*, Vol. 1, pp. 7.

Strand J. and A. Taraldset (1991), "The Valuation of Environmental Goods in Norway: a Contingent Valuation Study with Multiple Bias Setting", Working Paper, Department of Economics, University of Oslo.

US EPA (1999), *The Benefits and Costs of the Clean Air Act 1990 to 2010*, EPA Report to Congress, Report EPA-410-R-99-001, November 1999.

US EPA (2004), *Final Regulatory Impact Analysis: Control of Emissions from Nonroad Diesel Engines*, EPA420-R-04-007, May 2004, Washington D.C.

Valent F, Little D, Tamburlini G, Barbone F. (2004), *Burden of Disease attributable to selected Environmental Factors and Injuries among Europe's Children and Adolescent,* Geneva, World Health Organization, 2004 (WHO Environmental Burden of Disease Series, No. 8).

Van Ganse E., L. Laforest, G. Pietri, J.P. Boissel, F. Gormand, R. Ben-Joseph and P. Ernst (2002), "Persistent Asthma: Disease Control, Resource Utilisation and Direct Costs", *European Respiratory Journal*, Vol. 20, pp. 260-267.

Vassanadunrongdee S., S. Matsnoka, and H. Shirakawa (2004), "Meta-analysis of Contingent Valuation Studies on Air Pollution-related Morbidity Risks", *Environmental Economics and Policy Studies*, Vol. 6, pp. 11-47.

Viscusi, W. K., W.A. Magat and J. Huber (1991), "Pricing Health Risks: Survey Assessments of Risk-Risk and Dollar-Risk Tradeoffs", *Journal of Environmental Economics and Management*, Vol. 21, No. 1, pp. 32–51.

Voorhees, A.S., A. Shunichi, R. Sakai and H. Sato (2000), "An Ex Post Cost-benefit Analysis of the Nitrogen Dioxide Air Pollution Control Program in Tokyo", *Journal of Air and Waste Management Association*, Vol. 50, Part 3, pp. 391-410.

Weiss K.B., P.J. Gergen and T.A. Hodgson (1992), "An Economic Evaluation of Asthma in the United States", *New England Journal of Medicine*, Vol. 326, pp. 862-866.

WHO (2004), "Health Aspects of Air Pollution – Results from the WHO Project 'Systematic Review of Health Aspects of Air Pollution in Europe'", WHO, Copenhagen

WHO (2005), "WHO Air Quality Guidelines – Global Update 2005", Report on a Working Group meeting, 18-20 October 2005, Bonn, Germany.

World Bank (2006), *World Development Indicators*, The World Bank, Washington D.C.

ANNEX 1 – WHO SUB-REGIONS

WHO region	Mortality stratum	Countries
AFR	D	Algeria, Angola, Benin, Burkina Faso, Cameroon, Cape Verde, Chad, Comoros, Equatorial Guinea, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Madagascar, Mali, Mauritania, Niger, Nigeria, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Togo
	E	Botswana, Burundi, Central African Republic, Congo, Côte d'Ivoire, Democratic Republic of the Congo, Eritrea, Ethiopia, Kenya, Lesotho, Malawi, Mozambique, Namibia, Rwanda, South Africa, Swaziland, Uganda, United Republic of Tanzania, Zambia, Zimbabwe
AMR	A	Canada, Cuba, United States of America
	B	Antigua and Barbuda, Argentina, Bahamas, Barbados, Belize, Brazil, Chile, Colombia, Costa Rica, Dominica, Dominican Republic, El Salvador, Grenada, Guyana, Honduras, Jamaica, Mexico, Panama, Paraguay, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago, Uruguay, Venezuela
	D	Bolivia, Ecuador, Guatemala, Haiti, Nicaragua, Peru
EMR	B	Bahrain, Cyprus, Iran, Jordan, Kuwait, Lebanon, Libyan Arab Jamahiriya, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, Tunisia, United Arab Emirates
	D	Afghanistan, Djibouti, Egypt, Iraq, Morocco, Pakistan, Somalia, Sudan, Yemen
EUR	A	Andorra, Austria, Belgium, Croatia, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Luxembourg, Malta, Monaco, Netherlands, Norway, Portugal, San Marino, Slovenia, Spain, Sweden, Switzerland, United Kingdom
	B	Albania, Armenia, Azerbaijan, Bosnia and Herzegovina, Bulgaria, Georgia, Kyrgyzstan, Poland, Romania, Serbia and Montenegro, Slovakia, Tajikistan, the former Yugoslav Republic of Macedonia, Turkey, Turkmenistan, Uzbekistan
	C	Belarus, Estonia, Hungary, Kazakhstan, Latvia, Lithuania, Republic of Moldova, Russian Federation, Ukraine
SEAR	B	Indonesia, Sri Lanka, Thailand
	D	Bangladesh, Bhutan, Democratic People's Republic of Korea, India, Maldives, Myanmar, Nepal
WPR	A	Australia, Brunei Darussalam, Japan, New Zealand, Singapore
	B	Cambodia, China, Cook Islands, Fiji, Kiribati, Lao People's Democratic Republic, Malaysia, Marshall Islands, Micronesia, Mongolia, Nauru, Niue, Palau, Papua New Guinea, Philippines, Republic of Korea, Samoa, Solomon Islands, Tonga, Tuvalu, Vanuatu, Viet Nam

A: very low child and adult mortality; B: low child and adult mortality; C: low child and high adult mortality; D: high child and adult mortality; E: high child and very high adult mortality. Source: Ezzati et al. (2004).