European Journal of Epidemiology (2006)
DOI 10.1007/s10654-006-9014-0

ENVIRONMENTAL EPIDEMIOLOGY

Apheis: Health impact assessment of long-term exposure to $PM_{2.5}$ in 23 European cities

Elena Boldo[1], Sylvia Medina[2], Alain LeTertre[2], Fintan Hurley[3], Hans-Guido Mücke[4], Ferrán Ballester[5], Inmaculada Aguilera[6] & Daniel Eilstein on behalf of the Apheis group[2]
[1]*Carlos III Institute of Health, Madrid, Spain;* [2]*InVS-National Institute of Public Health Surveillance, Saint Maurice, France;* [3]*Institute of Occupational Medicine, Edinburgh, UK;* [4]*WHO Collaborating Centre at the Federal Environmental Agency, Berlin, Germany;* [5]*Valencian School of Studies for Health, Valencia, Spain;* [6]*Andalusian School of Public Health, Granada, Spain*

Accepted in revised form 4 April 2006

Abstract. *Introduction:* Apheis aims to provide European decision makers, environmental-health professionals and the general public with up-to-date and easy-to-use information on air pollution (AP) and public health (PH). In the Apheis-3 phase we quantified the PH impact of long-term exposure to $PM_{2.5}$ (particulate matter $<2.5\ \mu m$) in terms of attributable number of deaths and the potential gain in life expectancy in 23 European cities. *Methods:* We followed the World Health Organization (WHO) methodology for Health Impact Assessment (HIA) and the Apheis guidelines for data collection and analysis. We used the programme created by PSAS-9 for attributable-cases calculations and the WHO software AirQ to estimate the potential gain in life expectancy. For most cities, $PM_{2.5}$ levels were calculated from PM_{10} measurements using a local or European conversion factor. *Results:* The HIA estimated that 16,926 premature deaths from all causes, including 11,612 cardiopulmonary deaths and 1901 lung-cancer deaths, could be prevented annually if long-term exposure to $PM_{2.5}$ levels were reduced to 15 $\mu g/m^3$ in each city. Equivalently, this reduction would increase life expectancy at age 30 by a range between one month and more than two years in the Apheis cities. *Conclusions:* In addition to the number of attributable cases, our HIA has estimated the potential gain in life expectancy for long-term exposure to fine particles, contributing to a better quantification of the impact of AP on PH in Europe.

Key words: Air pollution, Europe, Health impact assessment, Life expectancy, Mortality, $PM_{2.5}$

Introduction

Most epidemiological studies find a range of health outcomes to be consistently related to particulate matter [1, 2]. Time-series studies identify the health impact (e.g. mortality) of particulate air pollution in the preceding days, whereas cohort studies analyse the health effects due to long-term exposure to particulate matter. A recent World Health Organization review [3] concludes that ambient particulate matter (PM) *per se* is considered responsible for the health effects seen in large epidemiological studies relating ambient PM to mortality and morbidity. This conclusion is supported by toxicological evidence. These epidemiological studies provide exposure-response functions (ERFs) necessary for Health Impact Assessment (HIA).

On the other hand, one of the main strategies of the HEALTH 21 policy for the WHO European Region is to ensure the use of HIA, an important approach in public health to evaluate policies and to determine

Participants in the Apheis-3 network:
Coordinators: Sylvia Medina (Saint Maurice, France), Antoni Plasència (Barcelona, Spain).
Centres: France: Sylvie Cassadou (*Toulouse*), Pascal Fabre, Hélène Prouvost, Christophe Declercq (*Lille*), Daniel Eilstein (*Strasbourg*), Laurent Filleul (*Bordeaux*), Laurence Pascal (*Marseille*), Jean François Jusot (*Lyon*), Myriam D'Elf (*Rouen, Le Havre*), Agnès Lefranc, Benoit Chardon (*Paris*), Alain Le Tertre (*Saint-Maurice*). **Greece:** Antonis Analitis, Giota Touloumi, Klea Katsouyanni (*Athens*). **Hungary:** Anna Paldy, Eszter Erdei, Janos Bobvos (*Budapest*). **Ireland:** Pat Goodman, Luke Clancy (*Dublin*). **Israël:** Sarah Hellmann, Ayana Goren (*Tel Aviv*). **Italy:** Ursula Kirchmayer, Paola Michelozzi (*Rome*). **Poland:** Krystyna Szafraniec (*Cracow*). **Republic of Slovenia:** Tina Gale, Peter Otorepec, Mateij Gregoric (*Ljubljana/Celje*). **Romania:** Emilia Maria Niciu (*Bucharest*). **Spain:** Koldo Cambra, Eva Alonso, Francisco Cirarda, Teresa Martínez (*Bilbao*). Lucía Artazcoz, Antoni Plasència (*Barcelona*). Mercedes Martínez, Belén Zorrilla, Laura López, Ana Gandarillas, Elena Boldo, Laura Crespo (Madrid). Inmaculada Aguilera, Antonio Daponte (Seville). Ferrán Ballester, Carmen Iñíguez, José Luis Bosch (*Valencia*). **Sweden**: Bertil Forsberg, Bo Segerstedt, Lars Modig (*Stockholm/Gothenburg*). **United Kingdom:** Richard Atkinson, Ross Anderson *(London)*.
Steering Committee: Ross Anderson (London, UK). Emile de Saeger, Nikolaos Stilianakis (Ispra, Italy). Klea Katsouyanni (Athens, Greece). Michal Krzyzanowski (Bonn, Germany). Hans-Guido Mücke (Berlin, Germany). Joel Schwartz (Boston, USA).

their potential and actual impacts on public health [4]. In relation to air pollution, WHO encourages all European countries to report and exchange monitoring information to help assessment of health impacts of PM_{10} and $PM_{2.5}$ [5].

In this context, Apheis[1] (Air Pollution and Health: a European Information System) was created in 1999 to provide European policy and decision makers, environment and health professionals, the general public and the medias with an up-to-date, easy-to use information resource on air pollution and public health to help them make better-informed decisions about the political, professional and personal issues they face in this area.

To develop this information resource, Apheis has created a public-health surveillance system that generates information for HIAs of air pollution in Europe at the city and European level simultaneously, on an ongoing basis. During the first phase (Apheis-1, 1999–2000), this programme defined the best indicators for epidemiological surveillance of the effects of air pollution on public health in Europe, and developed its own guidelines for data collection and analysis [6].

Apheis carried out a first HIA during its second phase (Apheis-2, 2000–2001). Apheis chose PM_{10} (particles less than 10 μm in size) and Black Smoke (BS) as PM indicators to show that relatively moderate levels of air pollution in urban Europe have a non-negligible impact on public health. Just as an example, reducing the long-term exposure to PM_{10} by even very small and achievable amounts, such as 5 $\mu g/m^3$, would have prevented between 3300 and 7700 early deaths annually in 19 European cities [7, 8].

The Apheis-3 phase (2002–2003) included new sources of data on air pollution and health in its analysis [9]. In particular, in this new HIA Apheis-3 added data for $PM_{2.5}$ (PM with an aerodynamic diameter smaller than 2.5 μm) to the existing BS and PM_{10} measurements. $PM_{2.5}$ was included based on recent evidence [3, 10] and on the proposal about new limit $PM_{2.5}$ values within the European Commission (EC) legislation process. Urban $PM_{2.5}$ is associated with excess mortality and other health effects. These smaller particles, which of course constitute a subfraction of PM_{10}, are considered more dangerous to health (per $\mu g/m^3$) because they penetrate more deeply into the lung and may reach the alveolar region [11]. Also, they are more numerous, and have greater surface area, per unit mass, than coarse particles (i.e.: particles with a diameter between 2.5 and 10 μm).

Apheis-3 investigated cause-specific mortality (cardiopulmonary and lung-cancer deaths) as well as total mortality. In addition to calculating attributable number of deaths at a given point in time, Apheis-3 also calculated the potential gain in life expectancy in order to provide a dynamic picture of the effects of air pollution on health over subjects' lifetimes.

Methodology

Apheis is a dynamic European network of professionals involved in public health and environment. This network adopted WHO guidelines for environmental-health risk assessment [12], and followed the main steps in HIA [13] city by city and then comparatively: specify exposure, select health outcomes and ERFs, derive population baseline frequency measures for the health outcomes studied, and calculate the estimated number of attributable cases in the target population. We used Apheis guidelines for gathering and analysing data to ensure comparability of the data [6].

Our HIA provided estimates of the number of health events attributable to air pollution in the target population (23 European cities) assuming that there is a causal relationship between particulate pollution and the observed health effects.

Exposure measurements

Because the present HIA focused on the effects of long-term exposure, the relevant air pollution data were annual averages, which were available for 2000 and beyond in most of the cities. Automatic $PM_{2.5}$ measurements (TEOM) were available in 12 Apheis cities.

For HIA purposes, the ERFs were taken from a publication that used gravimetric methods [14]. $PM_{2.5}$ levels had to be inferred from automatic PM_{10} measurements in 23 Apheis cities. If available, a local conversion factor (ranging between 0.5 and 0.8), selected with the advice of the local air-monitoring network managers, was applied. If no local factor was available, 0.7 was used as default European conversion factor, recommended by the Apheis Exposure Assessment Working Group as a mean value based on two recent publications. First, the revision and update of the so-called 1st European Daughter Directive, the 2nd Position Paper on Particulate Matter for the EC Clean Air for Europe (CAFE) programme, and second, a study analysing physical characteristics of particulate matter in Europe [15].

Bucharest and Budapest, where PM_{10} measurements were not available, converted Total Suspended Particulates (TSP) to PM_{10}, using local conversion factors, and then PM_{10} to $PM_{2.5}$, using the default European factor.

In order to assess the local validity of the 0.7 European conversion factor from PM_{10} used in cities where a local conversion factor was not available, we asked those cities with both PM_{10} and $PM_{2.5}$ direct measurements to provide both direct $PM_{2.5}$ measurements and converted $PM_{2.5}$ using the European conversion factor.

We had to correct the automatic PM_{10} measurements (β-attenuation and TEOM-Tapered Element

Oscillating Microbalance) used by most of the cities by a specific correction factor in order to compensate for losses of volatile material (organic compounds). A local correction factor chosen with the advice of the air-pollution network managers was used when available (ranging between 1 and 1.37); otherwise, the cities used the 1.3 European default correction factor recommended by the EC Working Group on Particulate Matter [16] and later by WHO [5] (Table 1).

Health outcomes and exposure-response functions

Health data were available for 1999 and beyond in most of the cities. For ERFs, we used average estimates of the more recent American Cancer Society (ACS) study based on the average of $PM_{2.5}$ concentrations at the start and finish of the ACS mortality follow-up period [14], and the health outcomes were studied for all-cause mortality, cardiopulmonary mortality and lung-cancer mortality (Table 2). Because the ACS study included only adults at age 30 or more, the estimation of attributable cases and the potential gain in life expectancy calculations in Apheis-3 were also limited to population of age 30 years and older.

HIA scenarios

Our HIA proposed a range of reference levels of particulate pollution used in different air pollution reduction scenarios. The benefits of reducing $PM_{2.5}$ to 20 and 15 $\mu g/m^3$ were selected at a time when discussions were taking place to set limit values for $PM_{2.5}$ as part of the CAFE legislation process at the European Commission. Since some cities already showed levels of $PM_{2.5}$ below those figures, we also proposed an additional scenario: a reduction by 3.5 $\mu g/m^3$, irrespective of current annual average levels (Table 2).

HIA tools

Number of long-term attributable cases

Based on the calculation of the attributable proportion, calculations of the number of long-term cases were made using an adapted Excel spreadsheet (EIS

Table 1. Measurement methods, correction and conversion factors used in Apheis-3

City	Measurement method			PM_{10} correction factor	Conversion factor from PM_{10} to $PM_{2.5}$
	PM_{10}[b]	$PM_{2.5}$[b]	TSP[b]		
Athens	β-attenuation			1.3*	0.3–0.63***[c]
Bilbao	β-radiation absorption			1.2[a]	0.7**
Bordeaux	TEOM[d] (50 °C)	TEOM (50 °C)		1[s]; 1.3[w]	0.67***
Bucharest			Gravimetric	X	0.7**
Budapest			β-ray-operation	XX	0.7**
Celje	TEOM (50 °C)			1.3*	0.7**
Cracow	β-gauge-monitor			1.25[a]	0.8***
Gothenburg	TEOM (50 °C)	TEOM (50 °C)		1.3*	0.66***
Le Havre	TEOM (50 °C)	TEOM (50 °C)		1[s]; 1.253[w]	0.7**
Lille	TEOM (50 °C)	TEOM (50 °C)		1.18[s]; 1.27[w]	0.66***
Ljubljana	TEOM (50 °C)			1.3*	0.7
London	TEOM	TEOM		1.3	0.7
Lyon	TEOM	TEOM		1.221[w]	0.7**
Madrid	β-attenuation			1[a]	0.51***
Marseille	TEOM (50 °C)	TEOM (50 °C)		1[s]; 1.13[w]	0.65***
Paris	TEOM	TEOM		1[s]; 1.37[w]	0.7**
Rome	β-gauge monitor			1.3*	0.7**
Rouen	TEOM (50 °C)	TEOM (50 °C)		1[s];1.22 [w]	0.7**
Seville	β-radiation-attenuation			1.13[a]	0.7**
Stockholm	TEOM (50 °C)	TEOM (50 °C)		1.2[a]	0.65***
Strasbourg	TEOM (50 °C)	TEOM (50 °C)		1[s]; 1.21[w]	0.7**
Tel Aviv	TEOM			1.3*	0.5***
Toulouse	TEOM (50 °C)	TEOM (50°C)		1[s]; 1.2[w]	0.65***

*For HIA purpose PM_{10} TEOM has been corrected by European default factor of 1.3.
**To convert PM_{10} to $PM_{2.5}$ the European default conversion factor 0.7 was used.
***To convert PM_{10} to a $PM_{2.5}$ local conversion factor was used.
[a]Derived from parallel PM_{10} measurements within the city.
[b]PM_{10}: PM < 10 μm; $PM_{2.5}$: PM < 2.5 μm; TSP: total suspended particulates.
[c]Range of $PM_{2.5}$ conversion factor, because month-specific factors were used.
[d]TEOM: Tapered Element Oscillating Microbalance.
s: summer; w: winter.
X: PM_{10} = TSP*0.6; XX: PM_{10} = TSP*0.58.

PA software, available in http://www.invs.sante.fr/epiinfo/logiciels/eispa.html) developed by the French surveillance system on air pollution and health, the so-called PSAS-9[2] programme coordinated by InVS, the French National Institute for Public Health Surveillance [17].

Gain in life expectancy

We calculated the expected gain in life expectancy at 30 years of age using Air Quality HIA software tool of the WHO European Centre for Environment and Health (AirQ software, available in http://www.euro.who.int/eprise/main/WHO/Progs/AIQ/activities/20050223_5). This programme uses a life-tables approach and is based on the same risk estimates from cohort studies as are used in estimating attributable cases (Table 2).

AirQ compares the actual life expectancy with the hypothetical life expectancy obtained for the baseline scenario. The greater is the difference, the greater is the relative importance of the cause. The gains in life expectancy are estimated by linking the following different sets of information:

- Change in annual average concentrations of $PM_{2.5}$
- A ERF linking annual average $PM_{2.5}$ with a % change (per $\mu g/m^3$) in mortality hazard rates (i.e. age-specific death rates)
- Demographic data (age-distribution, and age-specific death rates) of the target population.

Apheis assumed the same proportional hazard reduction for every age group (age >30) to be consistent with the findings of Pope et al. [14].

Results

The population covered by this HIA is nearly 36 million of inhabitants. Cities with $PM_{2.5}$ direct measurements showed annual mean concentrations that ranged between 9 $\mu g/m^3$ in Gothenburg and Stockholm (Sweden) and 18 $\mu g/m^3$ in Marseille (France). Cities where $PM_{2.5}$ was not measured directly had in general higher annual mean values, notably in Bucharest (Romania) and Tel Aviv (Israel) (Figure 1).

Figure 1 also shows that where direct and indirect values are available, the converted $PM_{2.5}$ levels using the European conversion factor from PM_{10} are quite similar to the direct levels, although sometimes slightly higher than them. Levels of $PM_{2.5}$ converted from PM_{10} follow PM_{10} patterns.

In terms of attributable cases, the Apheis-3 HIA estimated that 11,375 premature deaths, including 8053 cardiopulmonary deaths and 1296 lung-cancer deaths, could be prevented annually if long-term exposure to the annual mean of converted $PM_{2.5}$ levels were reduced to 20 $\mu g/m^3$ in each city; and that 16,926 premature deaths, including 11,612 cardiopulmonary deaths and 1901 lung-cancer deaths, could be prevented annually if long-term exposure to converted $PM_{2.5}$ were reduced to 15 $\mu g/m^3$ (Table 3).

Figure 2 shows the potential benefits of reducing annual $PM_{2.5}$ levels by 3.5 $\mu g/m^3$ in terms of number of premature deaths per 100,000 for all-causes mortality. All the cities would have benefited from this reduction in $PM_{2.5}$ levels, especially Budapest, Celje and Bucharest. Note that cities vary in their results because of differences in age-specific death rates and in the proportion of the overall population aged less than 30 years.

In terms of life expectancy, if the annual mean of converted $PM_{2.5}$ did not exceed 15 $\mu g/m^3$, the potential gain in life expectancy of a 30-year-old person would average between one month and more than two years, due to the reduction in total mortality (Figure 3).

Figure 4 illustrates for this last scenario the expected gain in life expectancy in one Apheis city (Seville, Spain). We chose this city as an example to show by how much this gain would affect each age. Note that the expected gain is unchanged until age 30 because mortality risks at age <30 are assumed to be unaffected. The gain would remain greater than 1 year until 60 years of age and would then start decreasing.

Table 2. Summary of data components used for health impact assessment of long-term exposure to $PM_{2.5}$[a] in Apheis-3

Health indicator	ICD10[b]	Tool	Relative risk (95% IC) (for 10 $\mu g/m^3$ increase)	Scenarios
Attributable cases				*Annual mean*
All-cause mortality	A00-Y98		1.06 (1.02–1.11)	Reduction to 20 g/m^3
Cardiopulmonary mortality	I10–I70 and J00–J99	PSAS-9	1.09 (1.03–1.16)	Reduction to 15 $\mu g/m^3$
Lung-cancer mortality	C33–C34	Excel spreadsheet	1.14 (1.04–1.23)	Reduction by 3.5 $\mu g/m^3$
Gain in life expectancy				*Annual mean*
All-cause mortality	A00-Y98		1.06 (1.02–1.11)	Reduction to 20 $\mu g/m^3$
Cardiopulmonary mortality	I10–I70 and J00–J99	AirQ	1.09 (1.03–1.16)	Reduction to 15 $\mu g/m^3$
Lung-cancer mortality	C33–C34		1.14 (1.04–1.23)	Reduction by 3.5 $\mu g/m^3$

[a]$PM_{2.5}$ indicates particles measuring less than 2.5 μm in diameter.
[b]ICD: International Classification of Diseases and Related Health Problems.

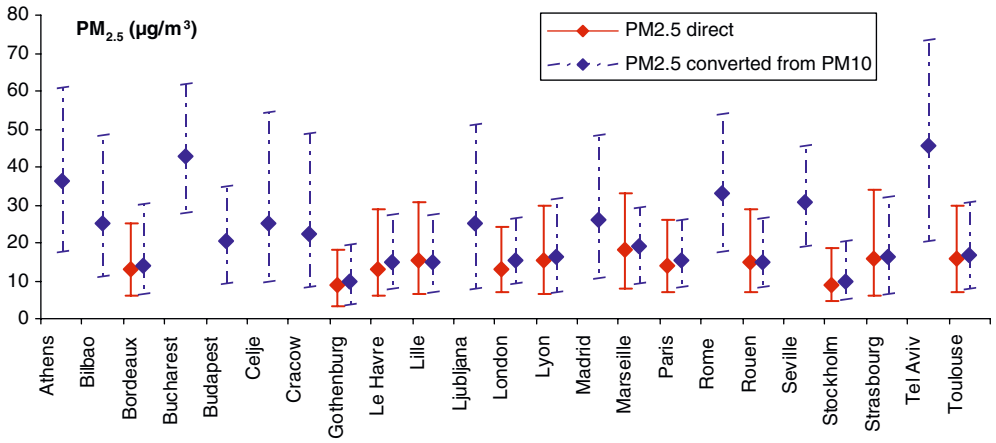

Figure 1. Annual mean levels and 5th and 95th percentiles of the distribution of $PM_{2.5}$* direct and $PM_{2.5}$ converted from PM_{10}* in 23 Apheis-3 cities. *$PM_{2.5}$ indicates particles measuring less than 2.5 μm in diameter; PM_{10}, particles measuring less than 10 μm in diameter.

Discussion

The new evidence provided by Apheis-3 confirmed the findings of Apheis-2 [7, 8] and other studies [18–21] that PM contributed in a non-negligible manner to the total burden of mortality in urban environments in Europe.

Methodological considerations

There are always uncertainties in the estimated benefits of removing a particular exposure. Some of these uncertainties are intrinsic, e.g. uncertainties in the estimation of the underlying ERF. In addition, the benefit may be achieved much later than predicted. In our case, lower air pollution levels would take years to be fully achieved and the lag-time between exposure reduction and the consequent reduction in mortality risks is not well-established yet, though intervention studies [22, 23] show substantial reductions in mortality risks in the years immediately following major reductions in ambient pollution, and evidence from the Six Cities cohort study shows a decrease in $PM_{2.5}$ levels in the more recent years of the study associated with reduced mortality risk [24].

Attributable cases are often interpreted as the preventable fraction, meaning those that would have been prevented had exposure been removed. However, caution should be used with such an interpretation, because the attributable risk estimation does not take competing risks into account. Removing one risk factor, e.g., air pollution, will increase the relative importance and contribution of other risks and causes of morbidity and mortality. Accordingly, for multicausal diseases it is well known that the sum of attributable cases across several risk factors does not add up to 100% but may be larger [9].

For the first time in Apheis, we also estimated the increase in life expectancy resulting from reductions in exposures to $PM_{2.5}$ pollution levels in different scenarios. The findings of this HIA suggest that relatively low concentrations of $PM_{2.5}$ over a long-term

Table 3. Summary findings of Apheis-3 HIAs in terms of potential reductions in the number of premature deaths and rates per 100,000 in 23 Apheis-3 cities

Air pollution indicator	Health indicator	HIA scenario	Potential long-term reduction in the number of deaths	
			Number of deaths	Number of deaths/100,000/year
$PM_{2.5}$[a]	All-cause mortality	Reduction to 20 $\mu g/m^3$	11,375	32
		Reduction to 15 $\mu g/m^3$	16,926	47
		Reduction by 3.5 $\mu g/m^3$	6355	18
	Cardiopulmonary mortality	Reduction to 20 $\mu g/m^3$	8053	22
		Reduction to 15 $\mu g/m^3$	11,612	32
		Reduction by 3.5 $\mu g/m^3$	4199	12
	Lung-cancer mortality	Reduction to 20 $\mu g/m^3$	1296	4
		Reduction to 15 $\mu g/m^3$	1901	5
		Reduction by 3.5 $\mu g/m^3$	743	2

[a]$PM_{2.5}$ indicates particles measuring less than 2.5 μm in diameter.

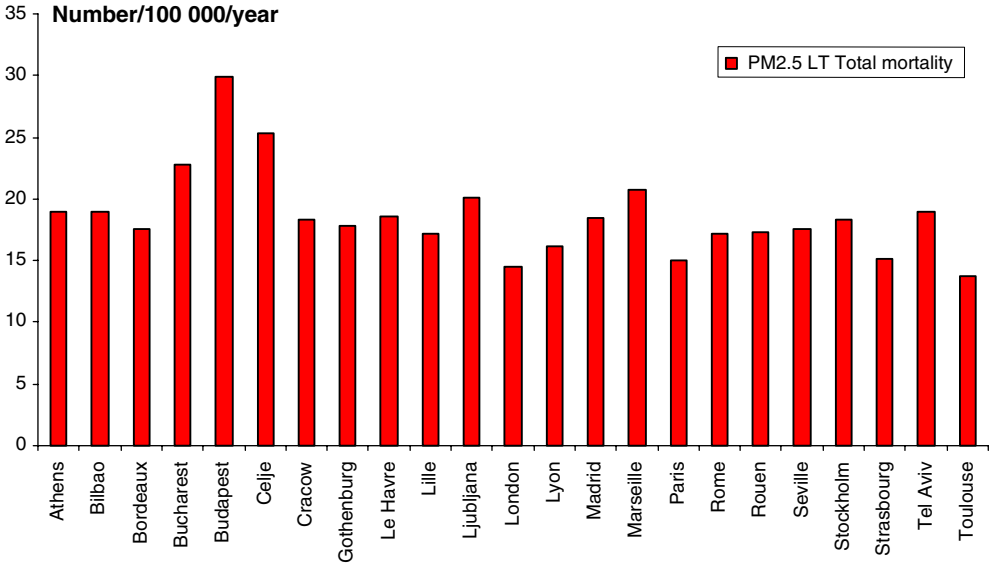

Figure 2. $PM_{2.5}$*: Long-term (LT) health impact on all-cause mortality in 23 Apheis-3 cities. Reductions by 3.5 $\mu g/m^3$. Number of deaths per 100,000 inhabitants. *$PM_{2.5}$ indicates particles measuring less than 2.5 μm in diameter.

exposure do reduce life expectancy in Europe. Other studies in the literature obtained similar conclusions when they analysed the effects of air pollution on life expectancy [25–28].

Opinions vary regarding the relative merits of estimating attributable cases or changes in life expectancy as means of expressing the impact of long-term exposure to air pollution on mortality. We used both approaches. Both approaches were also used in the cost-benefit analysis of the EC's CAFE programme, where the relative advantages and disadvantages were also discussed [29].

Regarding exposure data, HIA findings depend directly on the concentrations of measured particulate matter pollution. Cities where the $PM_{2.5}$ measurement data was not available used conversion factors (local or European) for calculating $PM_{2.5}$ levels from PM_{10} measurements. In cities where both sets of data were available, the annual mean of measured $PM_{2.5}$ concentration directly was slightly lower than the annual mean levels of $PM_{2.5}$ converted from PM_{10} calculated using the European conversion factor 0.7. It could imply that the European conversion factor is a little too high. Besides $PM_{2.5}$ conversion factor, correction factors (local or European) were used to correct automatic PM_{10} measurements. In general, local correction factors were slightly lower than the European default factor of 1.3 recommended

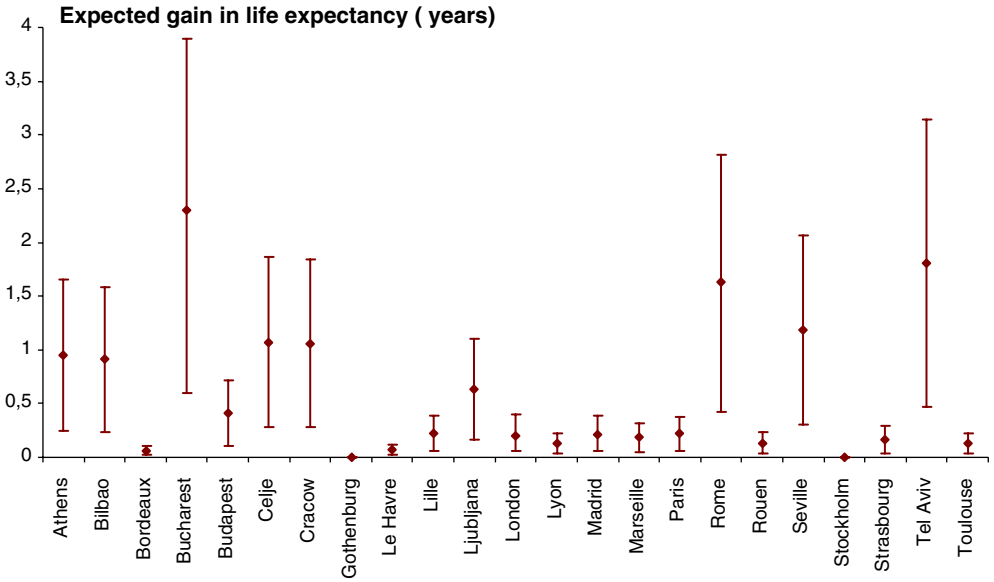

Figure 3. Expected gain in life expectancy at 30 years of age if the annual mean of converted $PM_{2.5}$* levels did not exceed 15 $\mu g/m^3$ in 23 Apheis-3 cities (95% confidence limits based on 95% CI of the Exposure–Response Functions). *$PM_{2.5}$ indicates particles measuring less than 2.5 μm in diameter.

by the EC Working Group on Particulate Matter. Estimates of corrected PM_{10} and converted $PM_{2.5}$ for HIAs of long-term exposure may thus be high.

We could conclude that, if there were no other uncertainties elsewhere, mortality estimates related to long-term exposure to PM_{10} and $PM_{2.5}$ could consequently be higher too. However the extent of overestimation is small, in absolute terms, and in relation to the many other sources of uncertainties that may contribute to under (or over) estimate the impact: number of air-pollution and health indicators considered for HIA, including or not sensitive subgroups of the population, or choice of primary ERF and its transferability.

Regarding the number of air pollution indicators considered, we only used $PM_{2.5}$ as a surrogate for the complex air-pollution mixture. In relation to health outcomes, cause-specific mortality was included together with all-cause mortality as complementary information to enrich the mortality picture. But all-cause mortality remains our first choice because it is more robust, not subject to misclassification and easier to obtain than morbidity data. Given that most of the cities applied a quality-control programme and given the low percentage of missing data for all-causes mortality, we consider that erroneous entries in the selection of cause of death did not affect the comparability of the data between cities.

Regarding health outcomes, it is likely that our HIA underestimates the full actual impact of fine particles in Europe. First, we only assessed the $PM_{2.5}$ impact on mortality, but morbidity was not analysed. The amount of disease due to long-term $PM_{2.5}$ exposure could be considerable in Europe [30–33]. Second, we did not consider the $PM_{2.5}$ impact on mortality under the age of 30 years, because valid ERFs were not available when we carried out this HIA. There is now sufficient evidence to infer a causal relationship between particulate air pollution and respiratory deaths in the post-neonatal period [34, 35]. Obviously, deaths at an early age affect substantially life expectancy in a population.

Our study did not focus on sensitive subgroups of the population. The ACS study [14] reported higher risks among people with lower educational status, and the ACS study itself included (relative to the US population as a whole) an under-representation of people with lower educational attainment, and so, arguably, an under-estimation of risks overall.

We used the most recent, well-established ERFs and the most powerful study for long-term $PM_{2.5}$ exposure [14]. It is an update of the ACS study covering 319,000 adults in 51 U.S. cities that doubled the follow-up time to more than 16 years, controlled for more confounding factors and used recent advances in statistical modelling. The ACS study considers variation in ambient pollution at the level of metropolitan area in the USA. These are large units, geographically and in terms of population. This study's findings confirm the associations observed in their previous study.

The main evidence that the estimate of 6% may not be too high comes from a series of cohort studies where pollution is characterised at a smaller spatial scale. These well-conducted studies, e.g. Hoek et al. [36], Jerret et al. [37], and Willis et al. [38] very consistently report higher coefficients, in the order of 13%–17% increase in mortality hazards, per 10 $\mu g/m^3$ $PM_{2.5}$. Also, the Harvard Six Cities study [24, 39] shows effects at this higher magnitude.

Preliminary findings of two European cohort studies suggested that mortality was associated with long-term average traffic-related air pollution, a major contributor to $PM_{2.5}$ [36, 40, 41]. Then, in the absence of robust European ERFs for long-term exposure to $PM_{2.5}$, the transferability of U.S. ERFs to the European countries seemed appropriate [42]. Nevertheless, the question of transferability of estimates between the U.S. and Europe raises uncertainties, since the toxicity of particulate matter pollution and populations may differ between these two continents. However, the contribution to the general $PM_{2.5}$ mixture of diesel particles from traffic is greater in Europe than in the U.S., and results from time series studies in both continents show higher risks, per $\mu g/m^3$ PM_{10}, in Europe than in the U.S. [43]. These facts suggest that by transferring the key coefficient from the U.S. to Europe we may

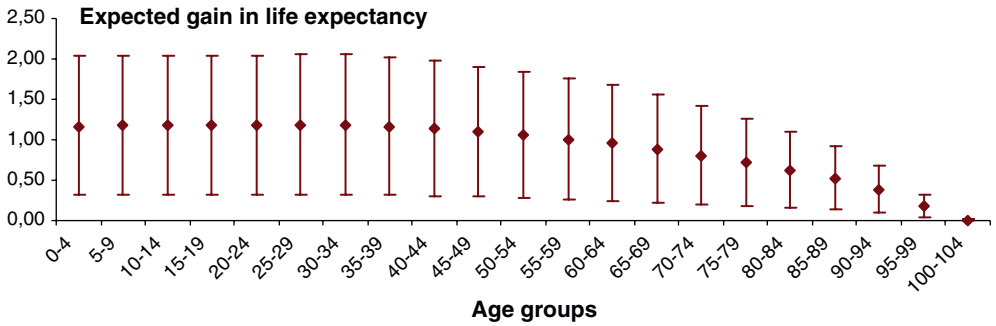

Figure 4. Expected gain in life expectancy if $PM_{2.5}$* annual mean levels did not exceed 15 $\mu g/m^3$ in Seville (Spain). *$PM_{2.5}$ indicates particles measuring less than 2.5 μm in diameter.

under-estimate, rather than over-estimate, a coefficient for Europe.

We should also be cautious when applying ERFs to cities whose PM concentrations exceed the range of the original study [14]. However, for most of the 23 cities studied, annual average $PM_{2.5}$ was within the range of the ACS study, the only marked exceptions being Bucharest and Tel Aviv. Furthermore, the general linearity of the ERFs within the ranges studied gives some reassurance that extrapolation above these ranges should not be seriously misleading [42].

When interpreting the findings on annual mortality, we should remember that the main effects of air pollution are associated with long-term exposure. Most of the acute effects on mortality are included in effects of long-term exposure and represent around 15% of these chronic effects, when judged in terms of the number of attributable cases [9]. But not all short-term health impacts are included in the long-term impacts [9, 44, 45]. Consequently, in our study omitting ERFs from time series also lead to under-estimating the short-term impact on mortality.

Policy implications

As regards exposure data, in addition to the existing PM_{10} monitoring networks, we recommend implementation of continuous $PM_{2.5}$ monitoring networks in all the participating Apheis cities to provide reliable, regular information on population exposure to ambient $PM_{2.5}$. In the meantime, more research is needed in each Apheis city and at the European level to define adequate local/European conversion/correction factors.

In relation to health data, substantial efforts should be made in most of the countries to reduce the time needed to obtain validated, comparable mortality and morbidity data.

Besides information on air pollution and health data, HIA requires information on ERFs. Questions about the transferability of ERFs would be avoided if the available ERFs of long-term exposure to $PM_{2.5}$ were based on European studies. We welcome that a major cohort study in Europe is one of the EC's priorities for environment and health research in the forthcoming Framework VII Research Programme.

As for the HIA scenarios we proposed, Apheis-3 revealed that reducing converted $PM_{2.5}$ levels to 15 $\mu g/m^3$ produces a benefit in terms of both total and cause-specific mortality that is over 30% greater than for a reduction to 20 $\mu g/m^3$. Apheis-3 also showed that even small reductions in annual average $PM_{2.5}$ levels (by 3.5 $\mu g/m^3$) may have substantial public health benefits.

Some countries have already established air quality standards for PM to protect the most sensitive groups of people, including infants and children, the elderly and persons with heart or lung disease. For example, California's annual PM standards (12 $\mu g/m^3$) are even more protective of human health than the corresponding set by US EPA (15 $\mu g/m^3$). Nevertheless, studies on large populations show a strong effect of $PM_{2.5}$ on mortality and these effects are expected to occur even below such low levels (ACS & Los Angeles ACS extension, [37]). Additionally, no threshold has been found in studies of acute effects of $PM_{2.5}$ [46] and besides we should remind that recent intervention studies [22, 23, 47, 48] do indicate the reduction in mortality and morbidity after decreases in air pollution.

In conclusion, in the context of the debate on the EC proposal for $PM_{2.5}$ Apheis adds further support to WHO's view that "it is reasonable to assume that a reduction of air pollution will lead to considerable health benefits" [10] and these benefits are expected to occur to levels well below those currently experienced in European cities. The Apheis-3 HIA has demonstrated the public health benefits of 15 $\mu g/m^3$ as a limit value for $PM_{2.5}$. However, because a significant health impact can be expected even at 15 $\mu g/m^3$, we advise to achieve further reductions in $PM_{2.5}$ levels, wherever practicable.

Acknowledgements

The huge amount of work behind the Apheis programme is the fruit of the generous and constructive input from all the members of the Apheis network. We wish to give our special thanks and appreciation to all of them. The Apheis programme was supported by the European Commission DG SANCO programme of Community action on pollution-related diseases (contract Nos. SI2.131174 [99CVF2-604]; SI2.297300 [2000CVG2-607]; SI2.326507 [2001CVG2-602] and the participating institutions in 12 European countries. Elena Boldo was supported by a grant from the Regional Ministry of Education (Order 7580/2003) and Regional Ministry of Health (Order 566/2001), Madrid Regional Government, Spain.

Notes

1. www.apheis.net
2. http://www.invs.sante.fr/psas9

References

1. Pope CAI, Burnett RT, Thurston GD, et al. Cardiovascular mortality and long-term exposure to particulate air pollution: epidemiological evidence of general pathophysiological pathways of disease. Circulation 2004; 109: 71–77.

2. Brunekreef B, Forsberg B. Epidemiological evidence of effects of coarse airborne particles on health. Eur Respir J 2005; 26: 309–318.
3. WHO. Health Aspects of Air Pollution with Particulate Matter, Ozone and Nitrogen Dioxide. Copenhagen: WHO Regional Office for Europe (EUR/03/5042688), 2003: 98 pp.
4. WHO. Health 21: The Health for All Policy Framework for the WHO European Region (European Health for All Series; No. 6). Copenhagen: Regional Office for Europe, 1999; 230 pp.
5. WHO. Review of Methods for Monitoring of PM2.5 and PM10. Report on a WHO Workshop. Berlin, Germany, 11–12 October, 2004: 95 pp.
6. Medina S, Plasencia A, Artacoz L, Quenel P, Katsouyanni K, Mucke HG, De Saeger E, Krzyzanowsky M, Schwartz J, and the contributing members of the Apheis group. Apheis Monitoring the Effects of Air Pollution on Public Health in Europe. Scientific report, 1999–2000. Saint-Maurice: Institut de Veille Sanitaire, 2001: 136 pp.
7. Medina S, Plasencia A, Artacoz L, Quenel P, Katsouyanni K, Mucke HG, De Saeger E, Krzyzanowsky M, Schwartz J, and the contributing members of the Apheis group. Apheis Health Impact Assessment of Air Pollution in 26 European Cities. Second year, 2000–2001. Saint-Maurice : Institut de Veille Sanitaire, 2002 : 225 pp.
8. Medina S, Plasencia A, Ballester F, Mucke HG, Schwartz J. Apheis: Public health impact of PM10 in 19 European cities. J Epidemiol Commun Health 2004; 58: 831–836.
9. Medina S, Boldo E, Saklad M, Niciu EM, Krzyzanowsky M, Frank F, Cambra K, Mucke HG, Zorrilla B, Atkinson R, Le Tertre A, Forsberg B, and the contributing members of the Apheis group. APHEIS Health Impact Assement of Air Pollution and Communications Strategy. Third year report, 2002–2003. Saint-Maurice : Institut de Veille Sanitaire, 2005: 232 pp.
10. WHO. Health Aspects of Air Pollution – Answers to Follow-up Questions from CAFE. Report on a WHO Working Group Meeting. Bonn, Germany, 15–16 January. Copenhagen: Regional Office for Europe (EUR/04/5046026), 2004: 78 pp.
11. WHO. Particulate Matter Air Pollution: How it Harms Health. Fact Sheet EURO/04/05. Berlin, Copenhagen, Rome, 2005: 4 pp.
12. WHO. Evaluation and Use of Epidemiological Evidence for Environmental Health Risk Assessment. Copenhagen: WHO Regional Office for Europe (EUR/00/5020369), 2000: 39 pp.
13. WHO. Quantification of Health Effects of Exposure to Air Pollution. Copenhagen: WHO, Regional Office for Europe (EUR/01/5026342), 2001: 34 pp.
14. Pope CAI, Burnett RT, Thun MJ, et al. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. JAMA 2002; 287: 1132–1141.
15. Van Dingenen R, Raes F, Putaud JP, et al. A European aerosol phenomenology-1: Physical characteristics of particulate matter at kerbside, urban, rural and background sites in Europe. Atmos Environ 2004; 38: 2561–2577.
16. EC Working Group Report on Particulate Matter. Guidance to Member States on PM10 Monitoring and Intercomparisons with the Reference Methods. 2002: 69 pp.
17. Le Tertre A, Quenel P, Eilstein D, et al. Short-term effects of air pollution on mortality in nine French cities: a quantitative summary. Arch Environ Health 2002; 57: 311–319.
18. Mindell J, Joffe M. Predicted health impacts of urban air quality management. J Epidemiol Commun Health 2004; 58: 103–113.
19. Martuzzi M, Galassi C, Ostro B, Forastiere F, Bertollini R. Health Impact Assessment of Air Pollution in the Eight Major Italian Cities. World Health Organization, 2002.
20. Kunzli N, Kaiser R, Medina S, et al. Public-health impact of outdoor and traffic-related air pollution: A European assessment. Lancet 2000; 356: 795–801.
21. Forsberg B, Hansson HC, Johansson C, Areskoug H, Persson K, Jarvholm B. Comparative health impact assessment of local and regional particulate air pollutants in Scandinavia. Ambio 2005; 34: 11–19.
22. Clancy L, Goodman P, Sinclair H, Dockery DW. Effect of air-pollution control on death rates in Dublin, Ireland: An intervention study. Lancet 2002; 360: 1210–1214.
23. Hedley AJ, Wong CM, Thach TQ, Ma S, Lam TH, Anderson HR. Cardiorespiratory and all-cause mortality after restrictions on sulphur content of fuel in Hong Kong: an intervention study. Lancet 2002; 360: 1646–1652.
24. Laden F, Schwartz J, Speizer FE, Dockery DW. Reduction in fine particulate air pollution and mortality: Extended follow-up of the Harvard Six Cities Study. Am J Respir Crit Care Med 2006; 173: 667–672.
25. Finkelstein MM, Jerrett M, Sears MR. Traffic air pollution and mortality rate advancement periods. Am J Epidemiol 2004; 160: 173–177.
26. Mechler R, Amann M, Schöpp W. A methodology to estimate changes in statistical life expectancy due to the control of particulate matter air pollution. Interim Reports. International Institute for Applied Systems Analysis (IIASA), 2002.
27. Committee on the Medical Effects of Air Pollutants (COMEAP). Long-Term Effects of Particles on Health. London, UK: COMEAP/20000/17, 2000.
28. Brunekreef B. Air pollution and life expectancy: is there a relation? Occup Environ Med 1997; 54: 781–784.
29. Hurley F, Hunt A, Cowie H, et al. Methodology for the Cost-Benefit Analysis for CAFE: Volume 2: Health Impact Assessment. Didcot, UK: AEA Technology Environment, 2005.
30. Brauer M, Hoek G, Van Vliet P, et al. Air pollution from traffic and the development of respiratory infections and asthmatic and allergic symptoms in children. Am J Respir Crit Care Med 2002; 166: 1092–1098.
31. Gehring U, Cyrys J, Sedlmeir G, et al. Traffic-related air pollution and respiratory health during the first 2 yrs of life. Eur Respir J 2002; 19: 690–698.
32. Kappos AD, Bruckmann P, Eikmann T, et al. Health effects of particles in ambient air. Int J Hygiene Environ Health 2004; 207: 399–407.
33. Ranzi A, Gambini M, Spattini A, et al. Air pollution and respiratory status in asthmatic children: Hints for a

locally based preventive strategy. AIRE study. Eur J Epidemiol 2004; 19: 567–576.
34. WHO. The Effects of Air Pollution on Children's Health and Development: A Review of the Evidence. Executive Summary, 2004: 4 pp.
35. Lacasana M, Esplugues A, Ballester F. Exposure to ambient air pollution and prenatal and early childhood health effects. Eur J Epidemiol 2005; 20: 183–199.
36. Hoek G, Brunekreef B, Goldbohm S, Fischer P, van den Brandt PA. Association between mortality and indicators of traffic-related air pollution in the Netherlands: a cohort study. Lancet 2002; 360: 1203–1209.
37. Jerrett M, Burnett RT, Ma R, et al. Spatial analysis of air pollution and mortality in Los Angeles. Epidemiology 2005; 16: 727–736.
38. Willis A, Jerrett M, Burnett RT, Krewski D. The association between sulfate air pollution and mortality at the county scale: An exploration of the impact of scale on a long-term exposure study. J Toxicol Environ Health A 2003; 66: 1605–1624.
39. Dockery DW, Pope CA, Xu X, et al. An association between air pollution and mortality in six U.S. cities. N Engl J Med 1993; 329: 1753–1759.
40. Nafstad P, Haheim LL, Oftedal B, et al. Lung cancer and air pollution: A 27 year follow up of 16,209 Norwegian men. Thorax 2003; 58: 1071–1076.
41. Nafstad P, Haheim LL, Wisloff T, et al. Urban air pollution and mortality in a cohort of Norwegian men. Environ Health Perspect 2004; 112: 610–615.
42. SCHER-Scientific Committee on Health and Environmental Risks. Opinion on ''New Evidence of Air Pollution Effects on Human Health and the Environment''. European Commission, Health & Consumer Protection Directorate, 2005: 15 pp.
43. Le Tertre A, Medina S, Samoli E, et al. Short-term effects of particulate air pollution on cardiovascular diseases in eight European cities. J Epidemiol Commun Health 2002; 56: 773–779.
44. Kunzli N, Medina S, Kaiser R, Quenel P, Horak F Jr., Studnicka M. Assessment of deaths attributable to air pollution: Should we use risk estimates based on time series or on cohort studies? Am J Epidemiol 2001; 153: 1050–1055.
45. Medina S, Plasencia A, Ballester F, Mucke HG, Schwartz J. Apheis: public health impact of PM10 in 19 European cities. J Epidemiol Commun Health 2004; 58: 831–836.
46. Schwartz J, Laden F, Zanobetti A. The concentration-response relation between PM(2.5) and daily deaths. Environ Health Perspect 2002; 110: 1025–1029.
47. Heinrich J, Hoelscher B, Frye C, et al. Improved air quality in reunified Germany and decreases in respiratory symptoms. Epidemiology 2002; 13: 394–401.
48. Friedman MS, Powell KE, Hutwagner L, Graham LM, Teague WG. Impact of changes in transportation and commuting behaviors during the 1996 Summer Olympic Games in Atlanta on air quality and childhood asthma. JAMA 2001; 285: 897–905.

Address for correspondence: Elena Boldo, ISCIII-National Centre for Epidemiology, C/Sinesio Delgado, 6, 28029, Madrid, Spain
Phone: +34-918222664; Fax: +34-913877815
E-mail: eiboldo@isciii.es