Improving Knowledge and Communication for Decision Making on Air Pollution and Health in Europe

Local city report

Le Havre

M. Corso[1], M. Blanchard[2], G. Falq[1], M. Pascal[1], A. Ung[1], O. Chanel[3], C. Declercq[1], S.Medina[1]

[1]French Institute for Public Health Surveillance, InVS, Saint-Maurice, France

[2]Regional Office of InVS, Rouen, France

[3]National Center for Scientific Research, GREQAM and IDEP, Marseille, France

Summary

The specific health impact assessment for Le Havre found that a significant health gain would be achieved by lowering the PM concentrations. The compliance with the WHO-AQG for PM10 (20µg/m^3) would induce a benefits on mortality and hospital admissions (3 deaths and 11 hospital admissions and avoided per year) in the study area of Le Havre. The associated monetary gain would be of more than € 250 000.

Lowering PM2.5 would have a higher impact. Compliance with the WHO-AQG of 10 µg/m^3 would postpone 54 deaths, corresponding to a gain in life expectancy of 0.3 years per inhabitants. Considering the reduced mortality, the associated monetary gain would exceed € 80 million.

The results from the present HIAs may help promoting measures aiming at reducing air pollutant emissions, especially traffic linked emissions, as health benefits are a powerful way of motivating changes in individuals comportments. In the district of Haute-Normandie, reduce air pollution and health effects are of great concern. Many **plan** local plans (plan to protect the atmosphere) or regional (second environmental health regional Plan) recommended actions to reduce air pollution: the objective is to implement actions helping to reduce and to control the exposures of air pollutant having a high impact on the health. The results of Aphekom would be an important information source for this plan in the area.

In addition, the Aphekom project was able to show that living near streets and roads carrying heavy traffic may have serious health effects, particularly on the development of chronic diseases. Aphekom investigated the effects of EU legislation to reduce the sulphur content of fuels (mainly diesel oil used by diesel vehicles, shipping and home heating) showing in 20 cities not only a marked, sustained reduction in ambient SO2 levels but also the resulting prevention of some 2,200 premature deaths valued at €192 million.

Together these findings show that policies aiming at reducing air pollution would be associated with a significant improvement in the health status and quality of life of European citizens.

Acronyms

Aphekom: Improving Knowledge and Communication for Decision Making on Air Pollution and Health in Europe

HIA: health impact assessment

O3: ozone

PM10: particulate matter with an aerodynamic diameter <10 µm

PM2.5: particulate matter with an aerodynamic diameter <2.5 µm

Introduction

Much has been done in recent years in European cities to reduce air pollution and its harmful effects on health. Yet gaps remain in stakeholders' knowledge and understanding of this continuing threat that hamper the planning and implementation of measures to protect public health more effectively.

Sixty Aphekom scientists have therefore worked for nearly 3 years in 25 cities across Europe to provide new information and tools that enable decision makers to set more effective European, national and local policies; health professionals to better advise vulnerable individuals; and all individuals to better protect their health.

Ultimately, through this work the Aphekom project hopes to contribute to reducing both air pollution and its impact on health and well being across European cities.

Section 1. Standardised HIA in 25 Aphekom cities

Health impact assessments have been used to analyze the impact of improving air quality on a given population's health. Using standardised HIA methods, the preceding Apheis project (1) (www.apheis.org) showed that large health benefits could be obtained by reducing PM levels in 26 European cities totalling more than 40 million inhabitants (2;3). Apheis thus confirmed that, despite reductions in air pollution since the 1990s, the public health burden of air pollution remains of concern in Europe.

In 2002, the Apheis project found that in Le Havre, 17 deaths per year could be avoided by reducing PM2.5 levels to 15 µg/m^3. This corresponded to a gain in life expectancy of 6 years cumulated for the whole population. Reducing PM10 levels to 20 µg/m^3 would avoid 4 deaths, 16 hospitalizations for respiratory and cardiac hospital admissions per year. In 2009, Enhis project (Environment and Health Information System) further found that reducing PM10 daily mean values to 20 µg/m3 would prevent 3.6 hospital respiratory admissions of children under 15 years old. Each reduction by 10 µg/m3 of the daily maximum 8-hour moving average ozone concentrations would delay 3.2 deaths per year in the general population in the study area, 1.3 from cardiovascular diseases, and 0.8 from respiratory causes. In terms of hospital admissions, this would represent 0.4 respiratory admissions in the adult (15-64 years old) population and 1.8 in the population over 64 years.

Building on the experience gained in the earlier Apheis and Enhis projects, Aphekom conducted a standardised HIA of urban air pollution in the 25 Aphekom cities totalling nearly 39 million inhabitants: Athens, Barcelona, Bilbao, Bordeaux, Brussels, Bucharest, Budapest, Dublin, Granada, Le Havre, Lille, Ljubljana, London, Lyon, Malaga, Marseille, Paris, Rome, Rouen, Seville, Stockholm, Strasbourg, Toulouse, Valencia and Vienna. In each participating centre, the project analysed the short-term impacts of ozone and PM10 on mortality and morbidity, as well as the long-term impacts of PM2.5 on mortality and life expectancy in populations 30 years of age and older.

This work shows that a decrease to 10 µg/m^3 of long-term exposure to $PM_{2.5}$ fine particles (WHO's annual air-quality guideline) could add up to 22 months of life expectancy for persons 30 years of age and older, depending on the city and its average level of $PM_{2.5}$.

Hence, exceeding the WHO air-quality guideline on $PM_{2.5}$ leads to a burden on mortality of nearly 19,000 deaths per annum, more than 15,000 of which are caused by cardiovascular diseases.

Aphekom also determined that the monetary health benefits from complying with the WHO guideline would total some €31.5 billion annually, including savings on health expenditures, absenteeism and intangible costs such as well being, life expectancy and quality of life.

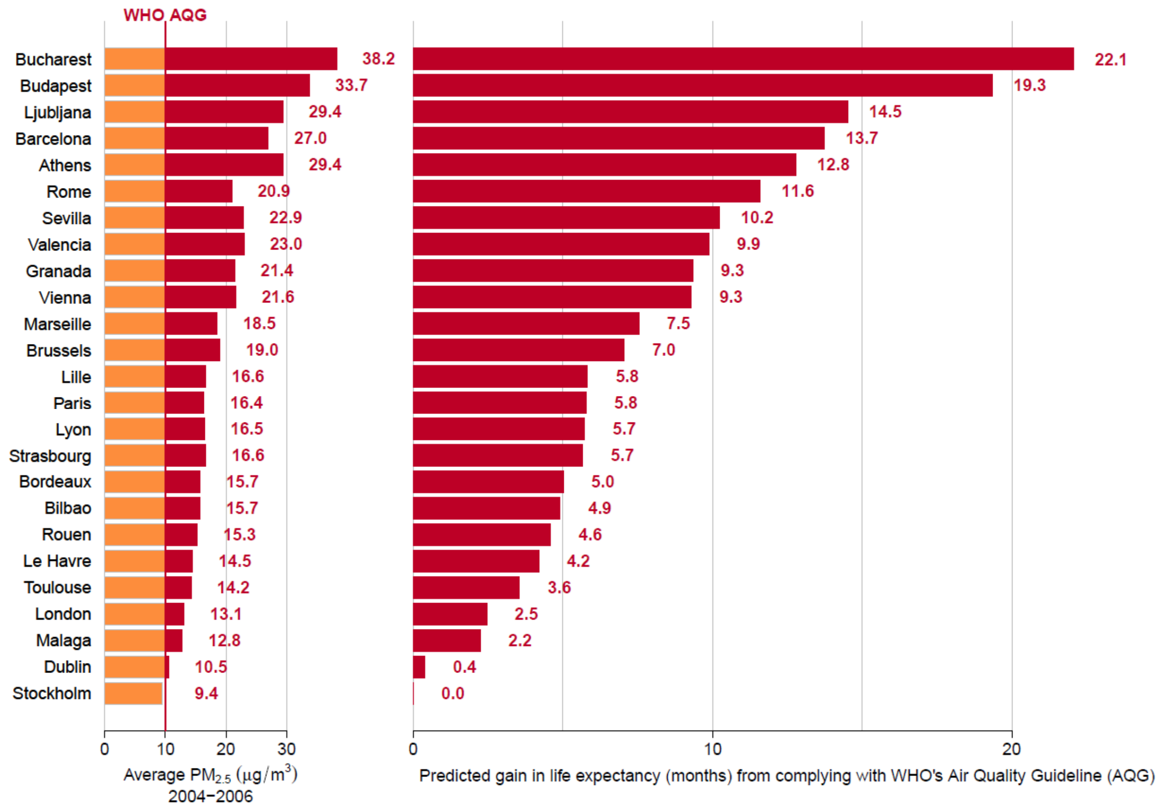


Figure 1 - Predicted average gain in life expectancy (months) for persons 30 years of age in 25 Aphekom cities for desease in average annual level of PM2.5 to 10 µg/m^3 (WHO's Air Quality Guideline)

1.1. Description of the study area for Le Havre

The Aphekom project has defined the study area so that data from local air-quality monitoring can provide a good estimate of the average exposure of the population in the study area, taking into account local land use, daily commuting and meteorology.

The study area of Le Havre is located on the right bank of the Seine estuary, 90km from Rouen and 220km from Paris and covers an area of 183km². Le Havre is naturally separated into two areas by a cliff. The "ville basse", or lower city, comprises the port, the city center, and the peripheral regions and the "ville haute", or upper city, is composed of residential district. The study area includes 16 municipalities (,Épouville, Fontaine-la-Mallet , Fontenay , Gainneville, Gonfreville-l'Orcher , Harfleur, Havre, Manéglise, Montivilliers , Notre-Dame-du-Bec, Octeville-sur-Mer, Rogerville, Rolleville, Sainte-Adresse, St-Laurent-de- Brèvedent, Saint-Martin-du-Manoir). Geographically, Le Havre has a strategic position as it faces one of the busiest waterways in the world, the English Channel.

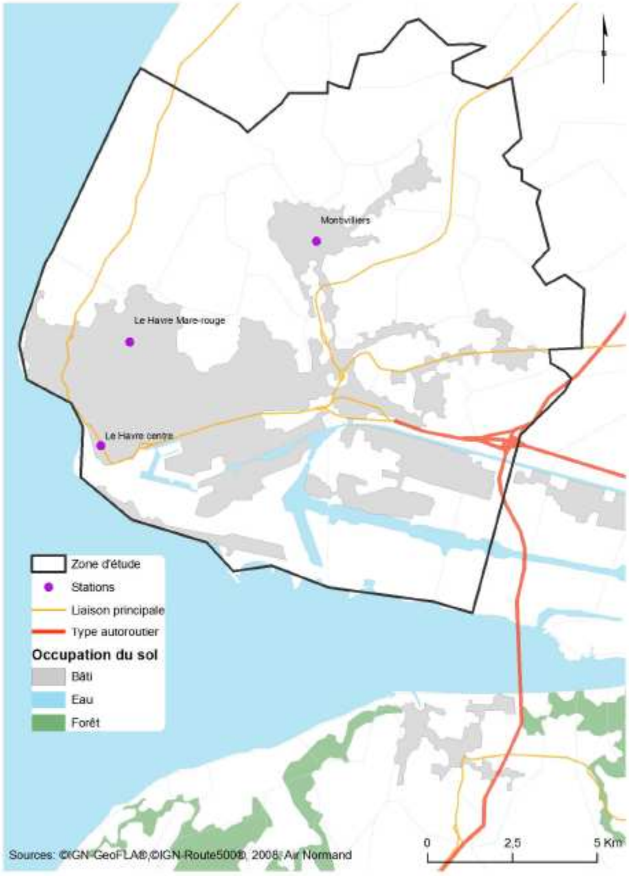


Figure 2 – Map of the study area of Le Havre

Climatology

It has an oceanic climate, mild and humid, with minimum and maximum temperatures of, respectively, 7.9℃ and 13.2℃.the westerly wind from the sea are dominant.

Population in the study area

In 2006, the population of this area was 254 638 inhabitants (15.9% of 65 years +).

Commuting

Approximatively, 90% of employed of the urban unit of le Havre remained there for work.

1.2. Sources of air pollution and exposure data

Sources

Like in all the agglomeration, air quality result from industry, transport and heating discharge. Nevertheless, due to the presence of a huge industrial area close to the study area, the air quality is mainly dependent of the industrial emissions. Moreover, its port is the second busiest in France and the first seaport for containers traffic.
Industrial emissions, like SO_2, show a trend toward a decrease over the last years, but levels of pollutants near industries are above limit values. Levels of PM10 are stable and ozone levels vary from one year to the next according to the sunning.

Table 1 – Main sources of air pollution (% t/year)(Source Air Normand inventory, 2009)

Pollutant	shaper industy	Production/ conversion/ energy distribution	Residential/ tertiary sector	Road transport	Maritime transport	Farming	Waste management
SO2	9,53%	77,66%	0,44%	0,04%	10,25%	0,02%	2,07%
NOx	12,36%	60,20%	1,89%	7,43%	17,52%	0,19%	0,42%
PM10	13,03%	52,57%	8,04%	7,99%	7,57%	1,93%	8,87%

Exposure data

A permanent automated air pollution network (Air Normand) provides air pollution data. For build the exposure indicator for ozone 3 stations were used for the period 2004-2006, 2 urban Monitors (Le Havre centre and Mare-Rouge) and 1 Suburban Monitor (Montvilliers). Ozone concentrations are measured by Ultraviolet photometric method.
PM10 and PM2.5 are measured in 2 urban stations (Le Havre centre and Mare-Rouge), by automatic analyser TEOM (Tapered Element Oscillating Microbalance).

After consultation of the reference laboratory in France for methods of measuring PM10 and PM2.5, we used two correction factors for respectively short and long term HIA calculations:
- In winter (increased levels of PM): 1.253
- In summer (moderate levels of PM): 1

These factors were based on comparative locally measurements between gravimetric and TEOM methods.

Corrected PM10 and PM2.5 annual mean have been calculated as the arithmetic mean of the annual concentrations of the three urban stations.

The daily maximum ozone 8-hours concentrations have been calculated as the arithmetic mean of the maximum 8-hour moving averages of the stations.

Corrected PM10 annual mean were below the limit value for 2005 (40µg/m^3), but higher than the WHO value (20µg/m^3). The daily average of PM10 have been higher than 20µg/m3 during 411 days between 2004 and 2006.

The daily maximum 8-hour moving average has been higher than 100µg/m^3 during 81 days between 2004 and 2006.

Daily 8-hour maximum ozone levels show a large variability between winter and summer (figure 3), while daily corrected PM10 and PM2.5 levels show a smaller variability (figures 4 and 5).

Table 2 – Daily mean levels, standard deviation and 5th and 95th percentiles for air pollutants (2004-2006)

Pollutant	Daily mean (µg/m^3)	Standard deviation (µg/m^3)	5th percentile (µg/m^3)	95th percentile (µg/m^3)
Ozone (daily 8h max)	67	25	24	108
PM10 corrected (daily average)	23	10	12	42
PM2.5 corrected (daily average)	14	9	7	31

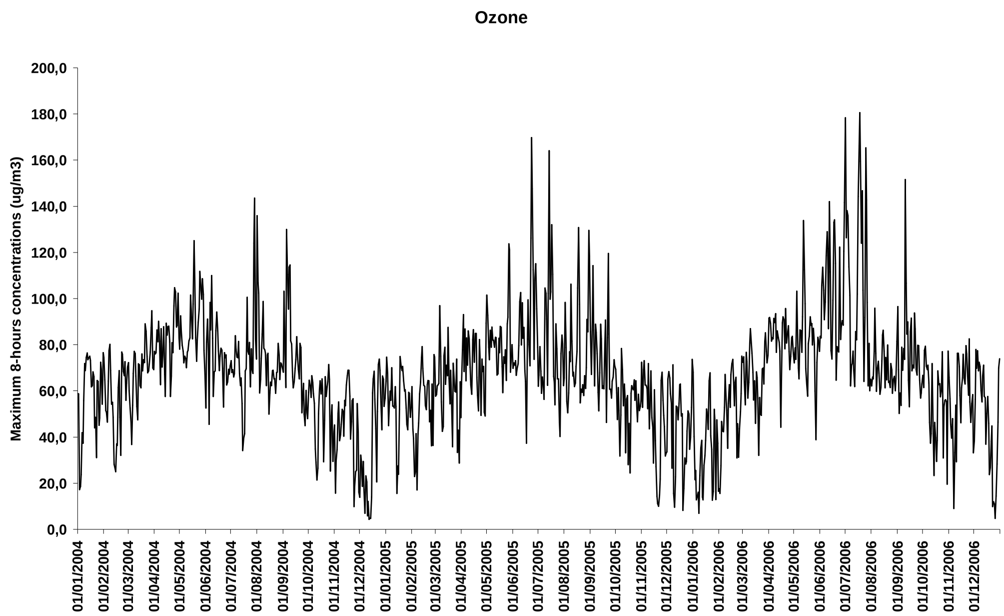


Figure 3 – Ozone concentration in the study area

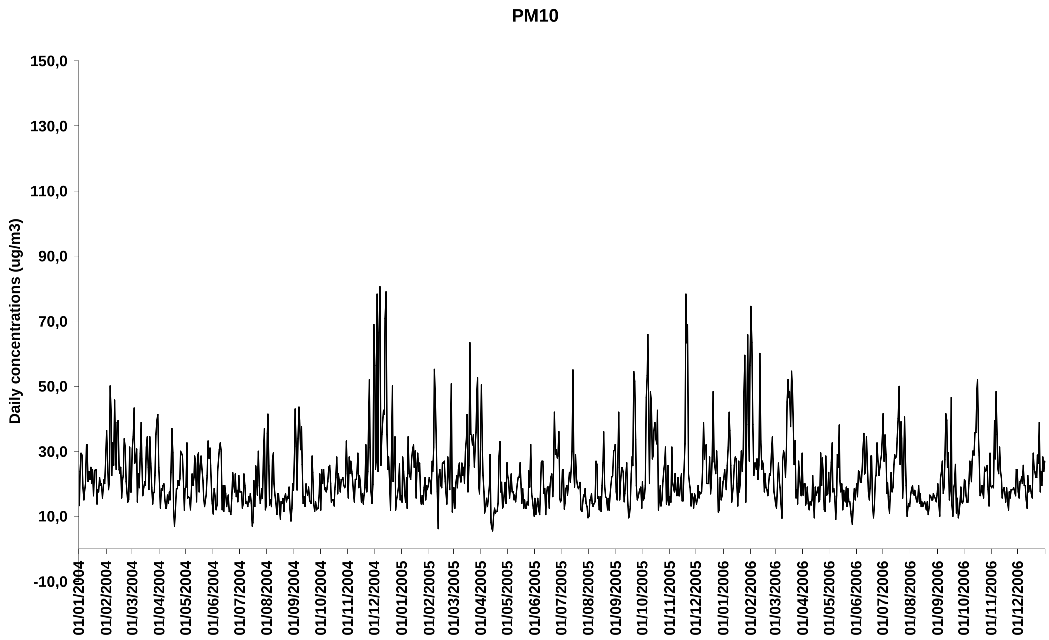


Figure 4 – PM10 concentration in the study area

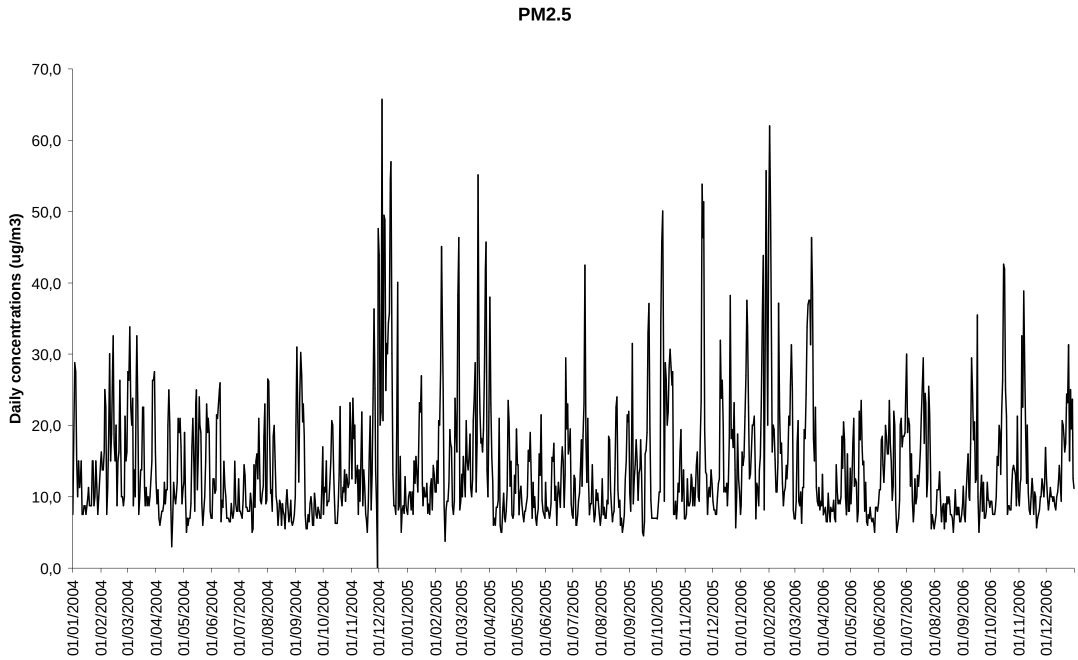


Figure 5– PM2.5 concentration in the study area

1.3. Health data

- Mortality data were provided by the Information Department specialised in mortality data (CepiDC) at the National Health and Medical Research Institute (INSERM) for years 2004 to 2006. There are no missing data, and a quality control program is applied. Death causes for years were coded according to ICD-10.

- Hospital admissions data for cardiovascular and respiratory diseases were extracted by the French Institute of Public Health (InVS) from the hospital information system PMSI (Programme de médicalisation des systèmes d'information) for public and private hospitals in Rouen. Respiratory, Cardiac and diseases are coded with ICD10 and available for years 2004 to 2006.

The number of deaths in the general population (non-external mortality) was 2 041 (annual rate 831 per 100,000).

Table 3 – Annual mean number and annual rate of deaths and hospitalizations per 100 000 inhabitants (2004-2006)

Health outcome	ICD9	ICD10	Age	Annual mean number	Annual rate per 100 000
Non-external mortality*	< 800	A00-R99	All	2 041	831
Total (including external mortality)	000-999	A00-Y98	> 30	2 120	1 442
Cardiovascular mortality	390-429	I00-I52	> 30	536	364
Cardiac hospitalizations	390-429	I00-I52	All	2 526	1 029
Respiratory hospitalizations	460-519	J00-J99	All	2 557	1 042
Respiratory hospitalizations	460-519	J00-J99	15-64 yrs	797	325
Respiratory hospitalizations	460-519	J00-J99	≥ 65 yrs	849	346

*** Non-external mortality excludes violent deaths such as injuries, suicides, homicides, or accidents.**

1.4. Health impact assessment

Aphekom chose different scenarios to evaluate the health impacts of short- and long-term exposure to air pollution. The scenarios are detailed below for each air pollutant.

NOTE: Under no circumstances should HIA findings for the different air pollutants be added together because the chosen air pollutants all represent the same urban air pollution mixture and because their estimated health impacts may overlap.

The HIA method is detailed in Annex 1 and HIA tools are provided in http://si.easp.es/aphekom

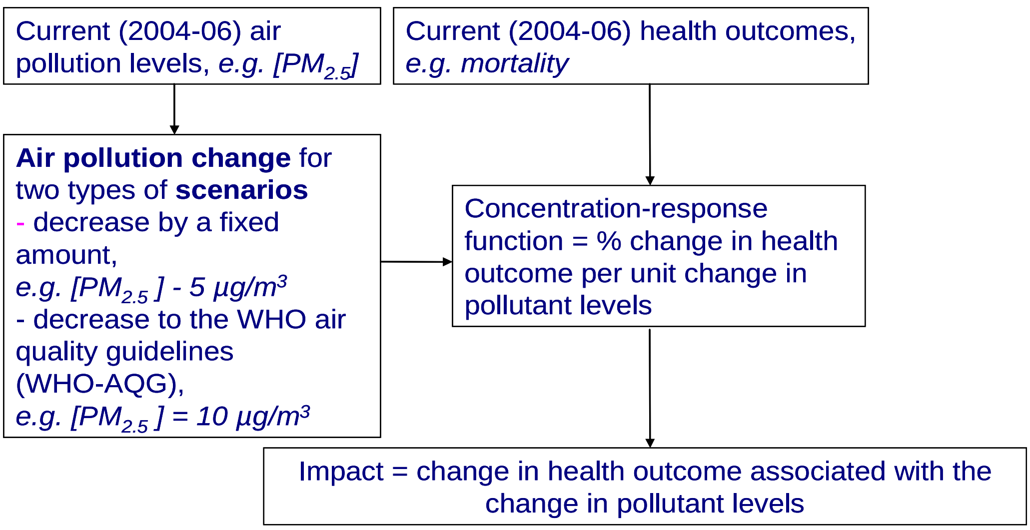


Figure 6 – Principles of local health impact assessment (HIA)

1.4.1. Short-term impacts of PM10

For PM10, we first considered a scenario where the annual mean of PM10 is decreased by 5 µg/m^3, and then a scenario where the PM10 annual mean is decreased to 20 µg/m^3, the WHO annual air quality guideline (WHO-AQG).
Decreasing PM10 annual mean by 5 µg/m^3 would postpone 6 deaths per year, 14 hospitalizations for respiratory diseases and 8 hospitalizations for cardiac diseases. Decreasing the annual mean to 20 µg/m^3 would postpone 3 deaths per year, 7 hospitalizations for respiratory diseases and 4 hospitalizations for cardiac diseases.

Table 4 – Potential benefits of reducing annual PM10 levels on total non-external* mortality

Scenarios	Total annual number of deaths postponed	Annual number of deaths postponed per 100 000
Decrease by 5 µg/m^3	6	3
Decrease to 20 µg/m^3	3	1

*** Non-external mortality excludes violent deaths such as injuries, suicides, homicides, or accidents.**

Table 5 – Potential benefits of reducing annual PM10 levels on hospitalizations

	Respiratory hospitalizations		Cardiac hospitalizations	
Scenarios	**Total annual number of cases postponed**	**Annual number of cases postponed per 100 000**	**Total annual number of cases postponed**	**Annual number of cases postponed per 100 000**
Decrease by 5 µg/m^3	14	6	8	3
Decrease to 20 µg/m^3	7	3	4	2

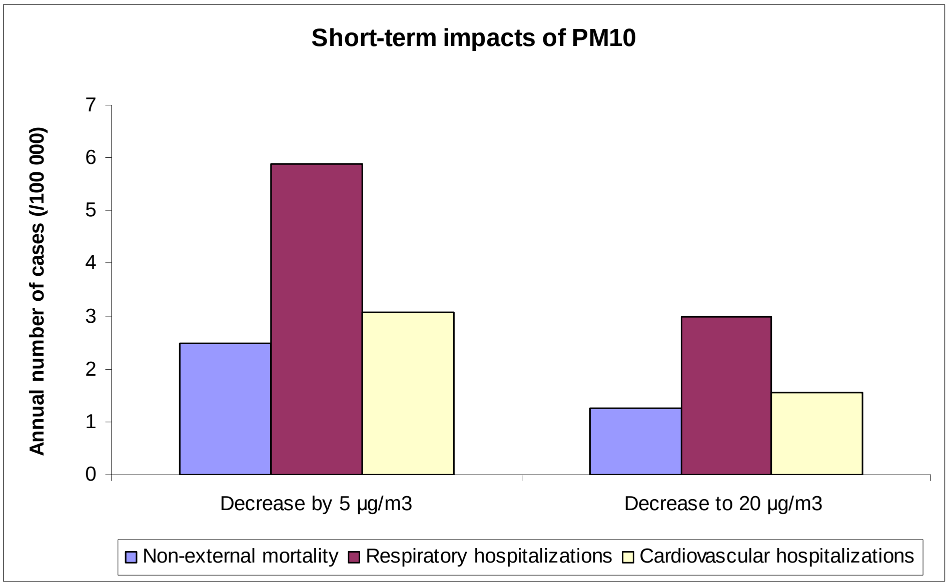


Figure 7 – Potential benefits of reducing annual PM10 levels on mortality and on hospitalizations

1.4.2. Short-term impacts of ozone

For ozone, WHO set two guideline values for daily the maximum 8-hours mean. The interim target value (WHO-IT1) is set at 160 µg/m^3 (daily 8h max). The purpose of the interim value is to define steps in the progressive reduction of air pollution in the most polluted areas. The second value, the air quality guideline value (WHO-AQG) is set at 100 µg/m^3.

We first considered a scenario where all daily values above 160 µg/m^3 were reduced to WHO-IT (160 µg/m^3), then a scenario where all daily values above 100 µg/m^3 were reduced to WHO-AQG (100 µg/m^3), and lastly a scenario where the daily mean is decreased by 5 µg/m^3.

Ozone values were below 160 µg/m^3 except for one day during the study period. Decreasing values above 100 µg/m^3 to 100 µg/m^3 would postpone 1 deaths and 1 hospitalizations for respiratory diseases for people older than 65.
Reducing all concentrations by 5 µg/m^3, would postpone 3 deaths and 2 hospitalizations for respiratory diseases for people older than 65.

Table 6 – Potential benefits of reducing daily ozone levels on total non-external* mortality

Scenarios	Total annual number of deaths postponed	Annual number of deaths postponed per 100 000
8h max daily values >160 µg/m^3 = 160 µg/m^3	0	0
8h max daily values >100 µg/m^3 = 100 µg/m^3	1	0.4
Decrease by 5 µg/m^3	3	1

*** Non-external mortality excludes violent deaths such as injuries, suicides, homicides, or accidents.**

Table 7 – Potential benefits of reducing daily ozone levels on hospitalizations

	Respiratory hospitalizations (15-64)		Respiratory hospitalizations (>64)	
Scenarios	Total annual number of cases postponed	Annual number of cases postponed per 100 000 inhabitants	Total annual number of cases postponed	Annual number of cases postponed per 100 000 inhabitants
8h max daily values >160 µg/m^3 = 160 µg/m^3	0	0	0	0
8h max daily values >100 µg/m^3 = 100 µg/m^3	0.1	0.1	1	2
Decrease by 5 µg/m^3	0.4	0.2	2	5

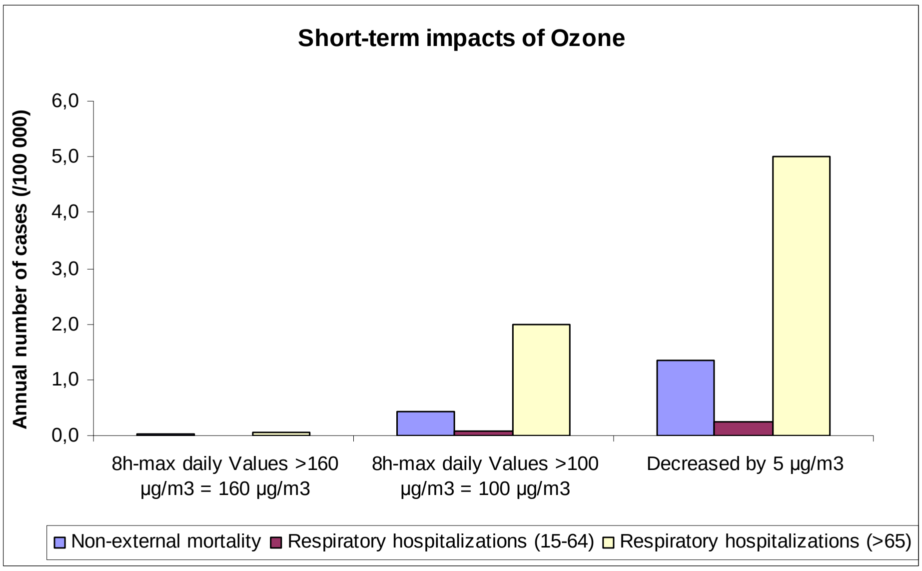


Figure 8 – Potential benefits of reducing daily ozone levels on mortality and on hospitalizations

1.4.3. Long-term impacts of PM2.5

For PM2.5, we first considered a scenario where the PM2.5 annual mean is decreased by 5 µg/m^3, and then a scenario where the PM2.5 annual mean is decreased to 10 µg/m^3 (WHO AQG).

Decreasing concentrations by 5 µg/m^3 would postpone 61 deaths, and 30 deaths for cardiovascular causes. This corresponds to a gain in life expectancy of 0.4 years per inhabitants.

Decreasing concentrations to 10 µg/m^3 would postpone 54 deaths, and 26 deaths for cardiovascular causes. This corresponds to a gain in life expectancy of 0.3 years per inhabitants.

Table 8 – Potential benefits of reducing annual PM2.5 levels on total non-external* mortality and on life expectancy

Scenarios	Total annual number of deaths postponed	Annual number of deaths postponed per 100 000 inhabitants	Gain in life expectancy
Decrease by 5 µg/m^3	61	41	0.4
Decrease to 10 µg/m^3	54	37	0.3

*** Non-external mortality excludes violent deaths such as injuries, suicides, homicides, or accidents.**

Table 9 – Potential benefits of reducing annual PM2.5 levels on total cardiovascular mortality

Scenarios	Total annual number of deaths postponed	Annual number of deaths postponed per 100 000 inhabitants
Decrease by 5 µg/m^3	30	20
Decrease to 10 µg/m^3	26	18

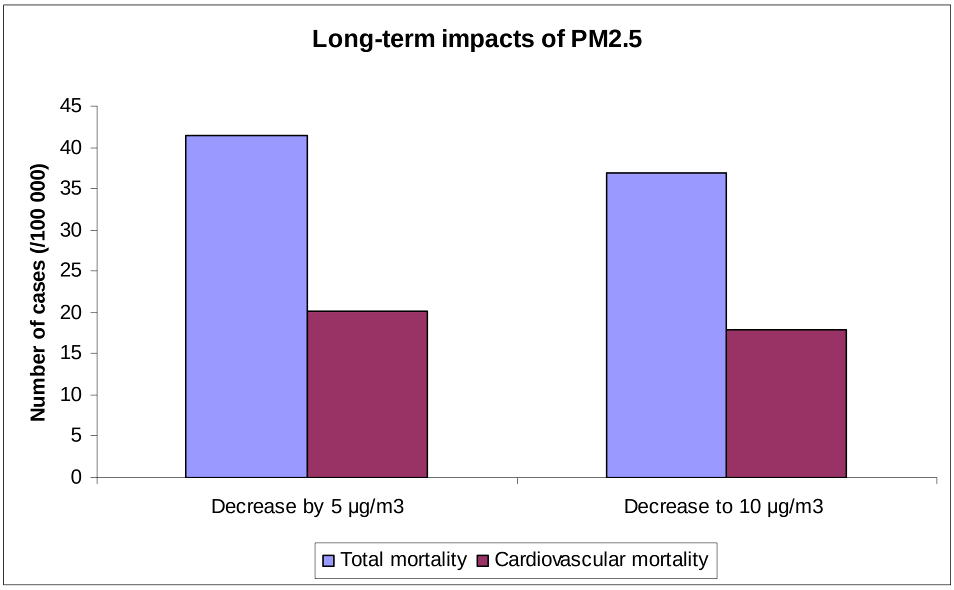


Figure 9 – Potential benefits of reducing annual PM2.5 levels on mortality

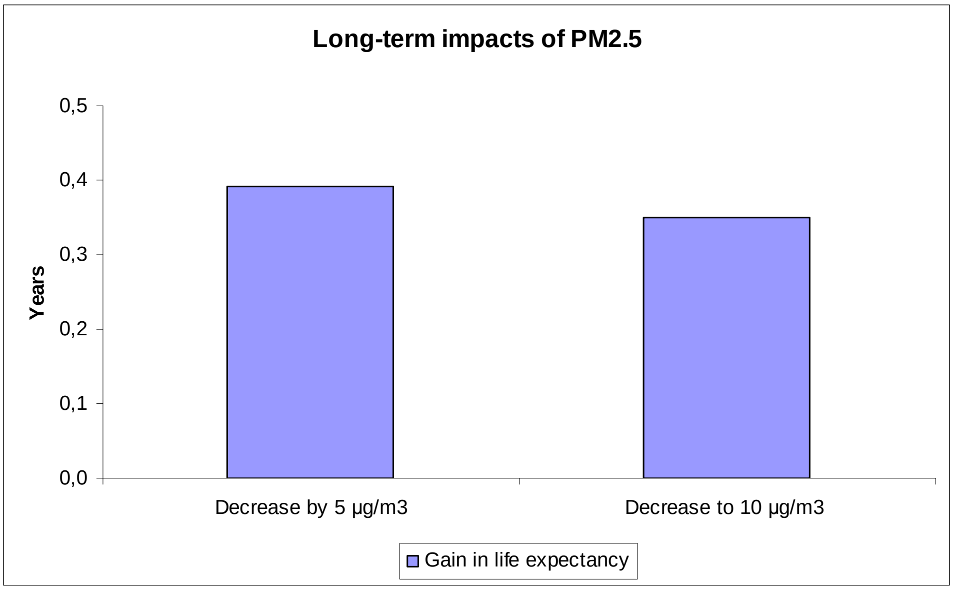


Figure 10 – Potential benefits of reducing annual PM2.5 levels on life expectancy

1.4.4. Economic valuation

These HIAs provide short- and long-term potential benefits on mortality of reducing air pollution as well as the short-term potential benefits on hospitalizations.

Mortality

The monetary values chosen to assess mortality benefits are going to differ depending on the short- or long-term nature of the exposure to air pollution (see Appendix 2).

For short-term impacts, the monetary value of €86,600 was chosen for each death. Decreasing PM10 concentration by 5 µg/m^3 would then correspond to a saving of 519 600€.
Decreasing PM10 concentrations to 20 µg/m^3 would correspond to a saving of € 259 800. Decreasing ozone concentrations above 100 µg/m^3 to 100 µg/m^3 would save € 86 600.

For long-term impacts, the monetary value of € 1,655,000 was chosen for each death. Decreasing PM2.5 concentrations by 5 µg/m^3 would then correspond to a saving of € 100 955 000. Decreasing PM2.5 concentrations to 10 µg/m^3 would correspond to a saving of € 89 370 000. Taking into account the gain in life expectancy would correspond to a saving of € 104 030 848 for the first scenario, and € 78 023 136 for the second.

NOTE: the valuation of mortality benefits is based on stated preferences studies and will use common values for all cities together. Indeed, accounting for differences in country's GNP per capita seems ethically unacceptable to stand for the valuation of life benefits.

Hospitalizations

The standard cost of illness approach is used for short-term hospitalizations, and consists in applying unit economic values to each case, including direct and indirect costs.

The method is detailed on Appendix 2. Considering that an hospitalization costs € 3 777, the savings would be of € 83 094 when reducing PM10 concentrations by 5 µg/m^3 and of € 41 547 when reducing PM10 concentrations to 20 µg/m^3. The gain associated to a reduction of ozone levels exceeding 100 µg/m^3 would be of € 3 777.

1.4.5. Interpretation of findings

Mortality data are highly reliable, and therefore do not represent a major source of uncertainty for the results of the present HIAs. On the contrary, hospital admission data present a major source of uncertainty because they include both emergency hospital admissions and planned hospital admissions that are certainly not temporally linked with the levels of air pollution. In consequence, the numbers of attributable hospital admissions are certainly over-estimated.

A significant health gain would be achieved by lowering the PM concentrations. The compliance with the WHO-AQG for PM10 (20µg/m^3) would induce a large benefits on mortality and hospital admissions (3 deaths and 11 hospital admissions and avoided per year). The associated monetary gain would be of more than € 250 000.

Lowering PM2.5 would have a higher impact of the quality of life. Compliance with the WHO-AQG of 10 µg/m^3 would postpone 54 deaths, corresponding to a gain in life expectancy of 0.3 years per inhabitants. Considering the reduced mortality, the associated monetary gain would exceed € 80 million.

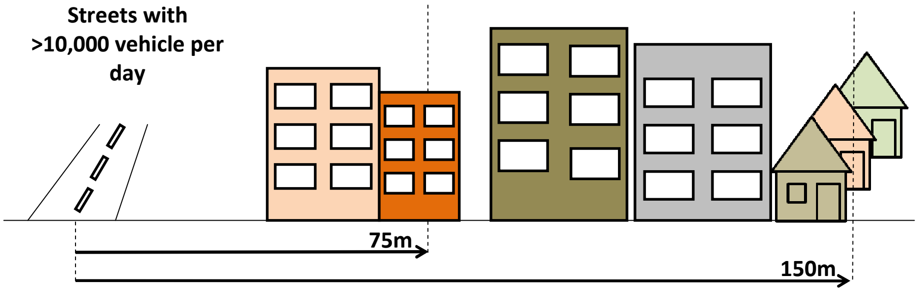
The results from the present HIAs may help promoting measures aiming at reducing air pollutant emissions, especially traffic linked emissions, as health benefits are a powerful way of motivating changes in individuals comportments.

Section 2. Health Impacts and Policy: Novel Approaches

Pollutants such as ultrafine particles occur in high concentrations along streets and roads carrying heavy traffic. And evidence is growing that living near such streets and roads may have serious health effects, particularly on the development of chronic diseases. Until now, however, HIAs have not explicitly incorporated this factor.

For this purpose, Aphekom has applied innovative HIA methods to take into account the additional long-term impact on the development of chronic diseases from living near busy roads. We also evaluated the monetary costs associated with this impact.

We first determined that, on average, over 50 percent of the population in the 10 European cities studied lives within 150 metres of roads travelled by 10,000 or more vehicles per day and could thus be exposed to substantial levels of toxic pollutants.



City	Population (Million. Hab)	PM_{10} annual average (ug/m^3)	% population within 75m (average 29%)	% population within 150m (average 52%)
Granada	0.24	34	14%	28%
Ljubljana	0.27	32	23%	47%
Bilbao	0.31	27	29%	59%
Sevilla	0.7	41	20%	38%
Valencia	0.74	46	44%	71%
Brussels	1.03	29	37%	64%
Stockholm	1.3	17	14%	30%
Barcelona	1.53	33	56%	77%
Vienna	1.66	25	36%	62%
Rome	2.81	37	22%	43%

Figure 11 ─ Estimated percentage of people leaving near busy roads

In the cities studied, our HIA showed that living near these roads could be responsible for some 15-30 percent of all new cases of: asthma in children; and of COPD (chronic obstructive pulmonary disease) and CHD (coronary heart disease) in adults 65 years of age and older.

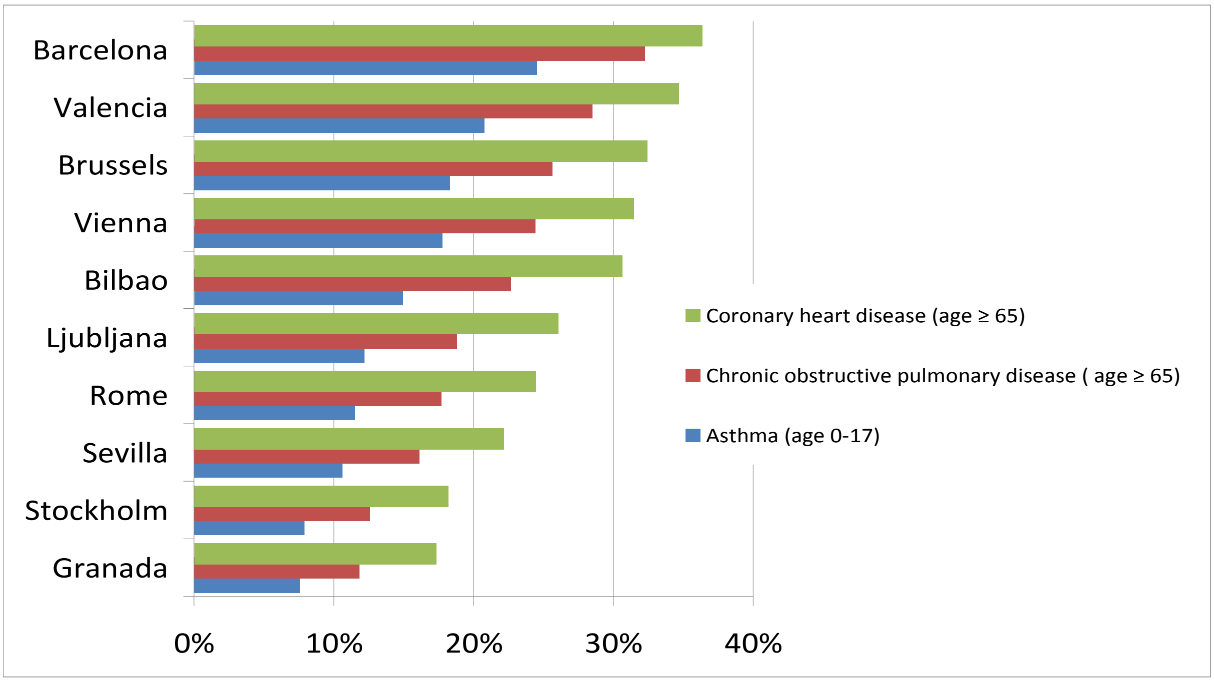


Figure 12 ─ Percentage of population with chronic diseases whose disease is attributable to living near busy streets and roads in 10 Aphekom cities

Aphekom further estimated that, on average for all 10 cities studied, 15-30 percent of exacerbations of asthma in children, acute worsening of COPD and acute CHD problems in adults are attributable to air pollution. This burden is substantially larger than previous estimates of exacerbations of chronic diseases, since it has been ignored so far that air pollution may cause the underlying chronic disease as well.

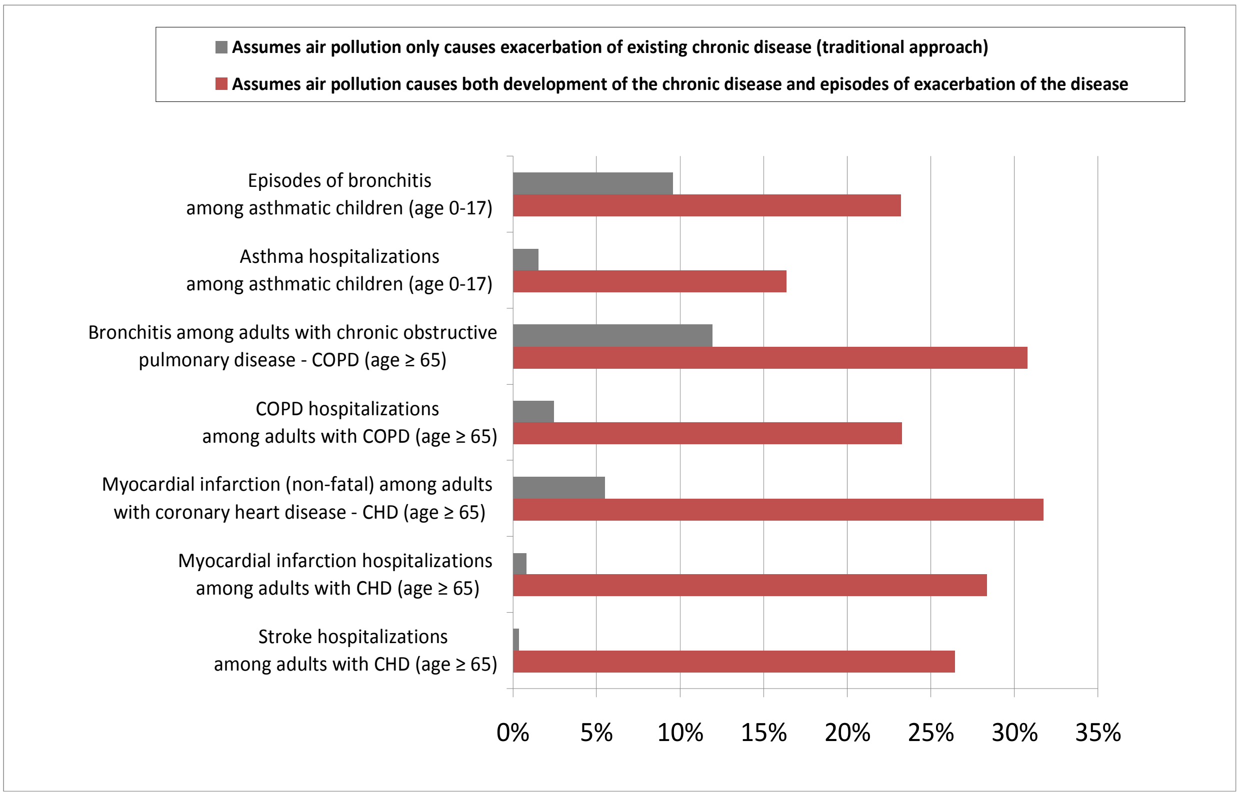


Figure 13 ─ Comparison of impact of air pollution on chronic diseases calculated using two different HIA approaches in Aphekom

In addition, for the population studied Aphekom estimated an economic burden of more than €300 million every year attributable to chronic diseases caused by living near heavy traffic. This burden is to be added to some € 10 million attributable to exacerbations of these diseases.

The economic valuation is not sufficiently robust at the city level from a HIA as well as an economic perspective to allow for local computations.

Section 3. Health Impacts of Implemented Policies in Air Pollution

As part of the work of the Aphekom WP6 an extensive review of the scientific literature on interventions, both legislative and coincidental which have resulted in reductions in air pollution, was conducted.
This review shows that air pollution interventions have been successful at reducing air pollution levels. It has also shown that there is consistent (significant) published evidence that most of these interventions have been associated with health benefits, mostly by way of reduced cardiovascular or respiratory mortality and or morbidity. Throughout the majority of reviewed interventions the found decrease in mortality exceeded by far the expected predicted figures based on observations European multicity studies.
This provides an informed scientific basis for decision and policy makers.

In addition to that, Aphekom WP6 investigated the effects of EU legislation to reduce the sulphur content of fuels (mainly diesel oil used by diesel vehicles, shipping and home heating). In detail the effect on air pollution levels of the implementation of the Council Directive 93/12/EEC and its amended version Council Directive 1999/32/EC including marine oils were analysed. The implementation of the two Council Directives encompassed three stages of implementation gradually reducing the sulphur content in certain fuels in the EU member states with stage (I) being implemented as laid down in the directive on 1st Oct. 1994, stage (II) on 1st Oct. 1996 and stage (III) on 1st July 2000.
This analysis showed not only a marked, sustained reduction in ambient SO2 levels, but also saved 2212 lives from all-cause mortality, 153 lives from respiratory-cause and 1312 lives from cardiovascular-cause mortality per year attributable to reduced ambient SO2 for 20 European cities, spread all across Europe, from the year 2000 onwards compared to the baseline period with no directive being implemented.

Air quality analysis

The general decreasing trend in daily urban background (UB) SO2 concentrations that has been observed across all centres (except the French centres excluding Paris) over the time period of the study is illustrated in Figure 14. Overall there was no clear step change in SO2 concentrations after implementation of the Directives; rather a gradual decline in SO2 levels was observed.
Furthermore city specific observations for Le Havre of decreasing UB SO2 levels are presented in Figure 15 showing seasonal averages of UB SO2

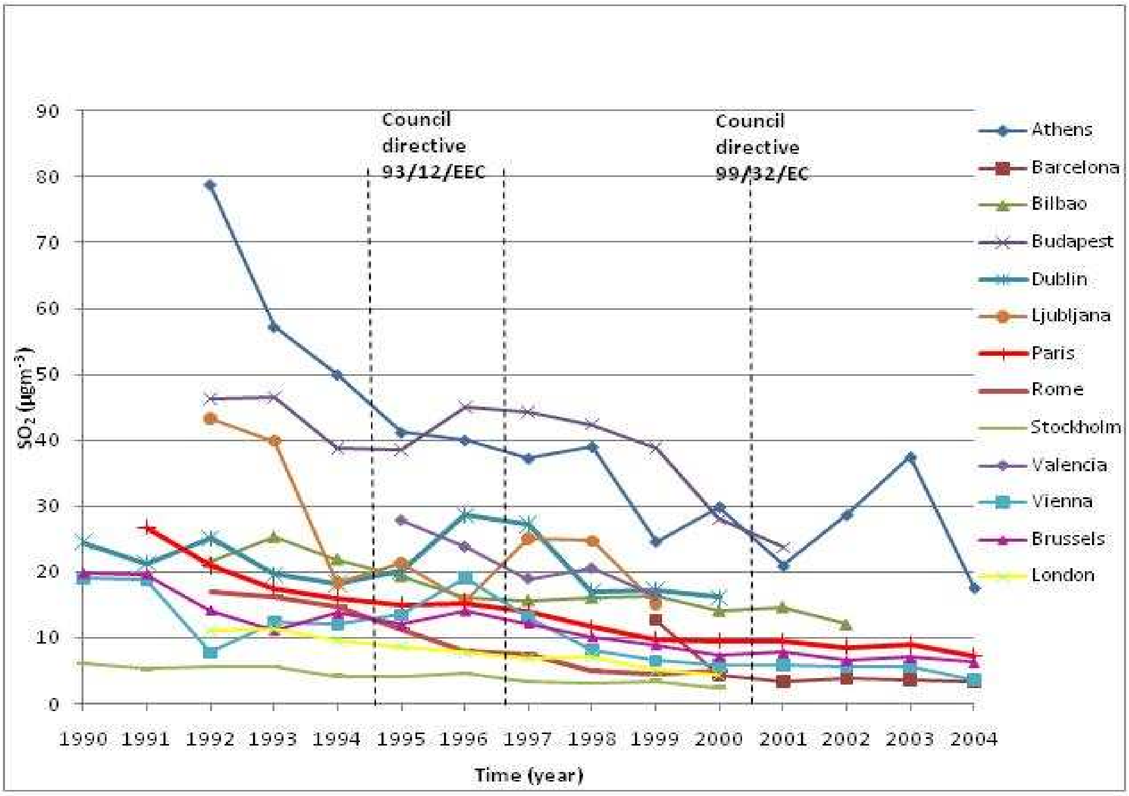


Figure 14 – Yearly urban background SO_2 averages for 13 Aphekom cities from 1990 to 2004

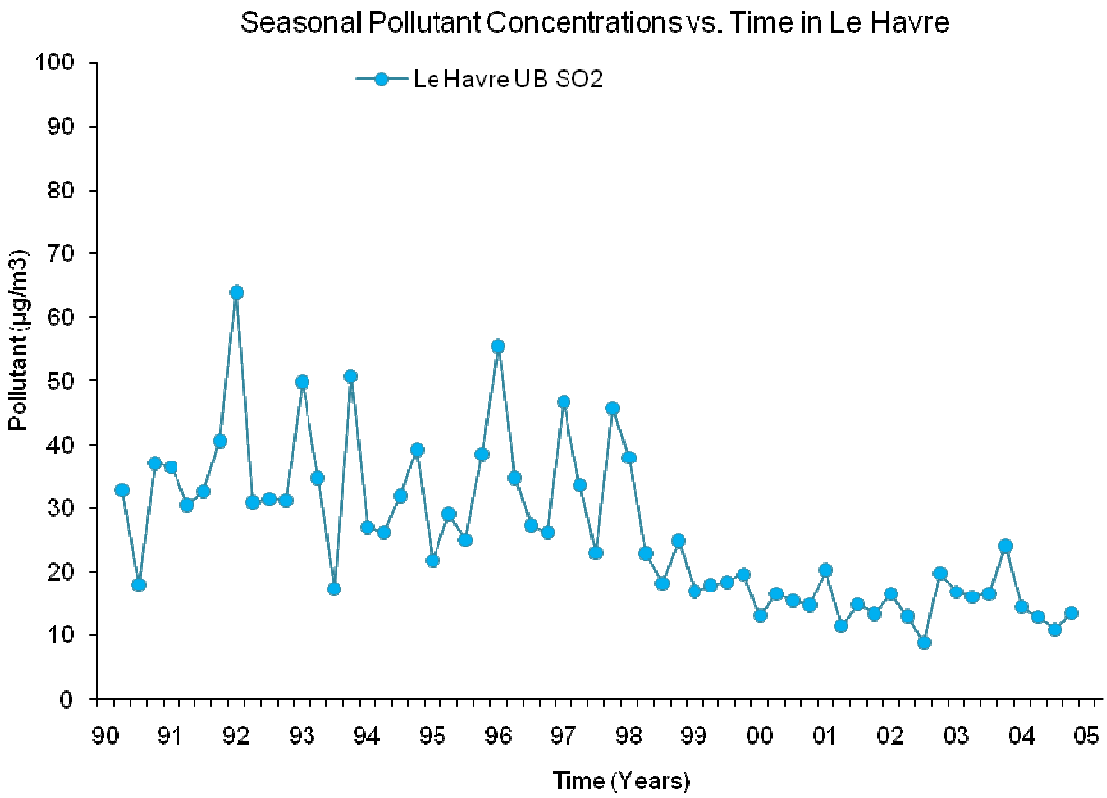


Figure 15: **Plot of seasonal urban background SO_2 averages for Le Havre from 1990 – 2001**

A rather abnormal peak of very high urban background SO_2 levels was observed simultaneously in a number of centres in the winters of 1995/6 and 1996/7. This does not mean that there are no outlying peaks now and then during the studied period in SO_2 levels for individual centres. The fact that those peaks were observed in many centres simultaneously and that individual levels were quite high compared to years before and after the observed peaks caught the attention of the WP6 team. Le Havre observed higher peaks in the winter of 1996/7, 1997/8 and the winter in the following year.
Based on the feedback received from the individual centres the most likely reason for the observed peaks happening simultaneously in a number of cities was cold wave in the winter months with peaking SO_2 levels. This coincided with observation made for a number of cities analysing daily averaged temperature data that showed prolonged periods with peaks in minimum temperatures reached in this time period. These observed cold waves went with increased fuel usage due to the increased space heating and electricity usage and as well as inversion. Another possible factor contributing to the observed SO_2 peaks could be that countries used up old stockpiles of fuel that did not comply with the directives. That might have happened independently from the cold wave or due to the fuel shortage during the prolonged cold weather.

Time-series analysis

It has to be noted that not all countries with collaborating cities have complied with the implementation dates laid down in the Council Directives due to various reasons, e.g. local derogations sought etc., and thus the implementation dates and the number of stages implemented are not all the same. Therefore the 14 centres including Athens, Bordeaux, Brussels, Dublin, Le Havre, Lille, London, Lyon, Marseille, Paris, Rome, Rouen, Stockholm and Strasbourg that implemented all three stages of the Council Directives were analysed separately.

The health data analysis showed no evidence of change of slope in the dose-response curve after implementation of the legislations and hence observed effects were related to level changes.

The implementation of the first stage in 1994 reduced annual deaths by 639 deaths from all causes, by 47 deaths from respiratory and by 361 deaths from cardiovascular causes compared to the baseline period prior to October 1994 with no directive being implemented.

The implementation of the 2nd stage in 1996 reduced annual deaths by 1093 deaths from all causes, by 83 deaths from respiratory and by 610 deaths from cardiovascular causes compared to the baseline period with no directive being implemented.

The implementation of the 3rd stage in 2000 reduced annual deaths by 1616 deaths from all causes, by 127 deaths from respiratory and by 889 deaths from cardiovascular causes compared to the baseline period with no directive being implemented.

On a city specific level for Le Havre the implementation of the first stage in 1994 reduced annual deaths by 0 death from all causes, by 0 death from respiratory and by 0 death from cardiovascular causes compared to the baseline period prior to October 1994 with no directive being implemented.

The implementation of the 2nd stage in 1996 reduced annual deaths by 10 deaths from all causes, by 1 death from respiratory and by 4 deaths from cardiovascular causes compared to the baseline period with no directive being implemented.

The implementation of the 3rd stage in 2000 reduced annual deaths by 23 deaths from all causes, by 2 deaths from respiratory and by 10 deaths from cardiovascular causes compared to the baseline period with no directive being implemented.

As a result on a city specific level for Le Havre (summarized in Table 1) and overall for the 14 cities that implemented all 3 stages of the fuel legislation it was found that the efficiency/effectiveness/impact of the legislation based on lives saved, if we didn't apply any regulation, increased throughout the different stages of implementation overtime with more lives being saved after implementation of the 2nd stage of implementation compared to the first stage and with more lives being saved after implementation of the 3rd stage of implementation compared to the 2nd one.

Table 10: Summary of lives saved per implementation stage (1-3)/intervention (and 95% Confidence Intervals) per year in Le Havre for different mortality groups compared the baseline period (<01.10.1994) with no legislation implemented

Time period	All cause mortality			Respiratory mortality			Cardiovascular Mortality		
	cases per year	95 CI -	95 CI +	cases per year	95 CI -	95 CI +	cases per year	95 CI -	95 CI +
Stage 1 [≥ 01.10.1994 and <01.10.1996]	0	0	1	0	0	0	0	0	0
Stage 2 [≥ 01.10.1996 and <01.07.2000]	10	3	16	1	0	2	4	1	8
Stage 3 [≥ 01.07.2000]	23	8	38	2	-1	4	10	3	18

Section 4. Sharing Knowledge and Uncertainties with Stakeholders

Uncertainties perceived by scientists, policy makers and other stakeholders can undermine their confidence in the findings of HIAs. For this reason, Aphekom has developed a method that helps them discuss and share their views on both the uncertainties in HIA calculations and their impact on the decision-making process.

In addition, to help decision makers draft policies on air quality and related environmental-health issues, Aphekom has developed a process, based on a deliberation-support tool, that helps frame and structure exchanges between stakeholders working together. Using this process enables them to propose and discuss multiple criteria for evaluating, prioritising and aligning their various needs, and for choosing actions that match their objectives and preferences.

Section 5. Overview of findings and local recommendations

The specific health impact assessment for Le Havre found that a significant health gain would be achieved by lowering the PM concentrations. The compliance with the WHO-AQG for PM10 (20µg/m^3) would induce a large benefits on mortality and hospital admissions (3 deaths and 11 hospital admissions and avoided per year). The associated monetary gain would be of more than € 250 000.

Lowering PM2.5 would have a higher impact. Compliance with the WHO-AQG of 10 µg/m^3 would postpone 54 deaths, corresponding to a gain in life expectancy of 0.3 years per inhabitants. Considering the reduced mortality, the associated monetary gain would exceed € 80 million.

The results from the present HIAs may help promoting measures aiming at reducing air pollutant emissions, especially traffic linked emissions, as health benefits are a powerful way of motivating changes in individuals comportments. In the district of Haute-Normandie, reduce air pollution and health effects are of great concern. Many plan local plans (plan to protect the atmosphere) or regional (second environmental health regional Plan) recommended actions to reduce air pollution: the objective is to implement actions helping to reduce and to control the exposures of air pollutant having a high impact on the health. The results of Aphekom would be an important information source for this plan in the area.

In addition, the Aphekom project was able to show that living near streets and roads carrying heavy traffic may have serious health effects, particularly on the development of chronic diseases. Aphekom investigated the effects of EU legislation to reduce the sulphur content of fuels (mainly diesel oil used by diesel vehicles, shipping and home heating) showing in 20 cities not only a marked, sustained reduction in ambient SO2 levels but also the resulting prevention of some 2,200 premature deaths valued at €192 million.

Together these findings show that policies aiming at reducing air pollution would be associated with a significant improvement in the health status and quality of life of European citizens.

Acknowledgements

The authors would like to thank Air Normand which provided the air quality data.

Appendix 1 – Health impact assessment

For each specific relationship between health outcomes and pollutants, the health impact function was

$$\Delta y = y_0(1 - e^{-\beta\Delta x})$$

Where Δy is the outcome of the HIA
y_0 is the baseline health data
Δx is the decrease of the concentration defined by the scenario
β is the coefficient of the concentration response function (β=log(RR per 10 µg/m^3)/10)

The impact of a decrease of the pollutant concentration on the life expectancy was computed using standard abridged (5-year age groups) life table methodology, using the mortality data for each age group. We applied a reduction factor to the mortality rate, noted ${}_nD_x$, according to

$${}_nD_x^{impacted} = {}_nD_x * e^{-\beta\Delta x}$$

Δx is the decrease of the concentration defined by the scenario
β is the coefficient of the concentration response function.

Concentration response functions (CRFs) were selected from the literature, favouring multi-cities studies located in Europe (Table 11).

Table 11 – Health outcome and relative risks used in the HIA

HIA	Health outcome	Ages	RR per 10 µg/m^3	Ref
Short-term impacts of PM10	Non-external mortality	All	1.006 [1.004-1.008]	(4)
	Respiratory hospitalizations	All	1.0114 [1.0062-1.0167]	(5)
	Cardiac hospitalizations	All	1.006 [1.003-1.009]	(5)
Short-term impacts of O_3	Non-external mortality	All	1.0031 [1.0017-1.0052]	(6)
	Respiratory hospitalizations	15-64	1.001 [0.991-1.012]	(4)
	Respiratory hospitalizations	>=65	1.005 [0.998-1.012]	(4)
Long-term impacts of PM2.5	Non-external mortality	>30	1.06 [1.02-1.11]	(7)
	Cardiovascular mortality	>30	1.12 [1.08-1.15]	(8)

PM10

For PM10, we first considered a scenario where the annual mean of PM10 is decreased by 5 μg/m^3, and then a scenario where the same PM10 annual mean is decreased to 20 μg/m^3, the WHO air quality guideline (WHO-AQG).
The exposure indicator of PM10 was the annual mean, calculated as the arithmetic mean of the daily concentrations of the selected stations. The corresponding Δx for the two scenarios are:

- Scenario 1, Δx = 5 μg/m^3

- Scenario 2, Δx = ($[PM10]_{mean}$ – 20 μg/m^3).
  Δx = 0 if $[PM10]_{mean}$ <20

Ozone

For ozone, WHO set two values for the daily maximum 8-hours mean. The interim target value (WHO-IT1) is set at 160 μg/m^3. The purpose of the interim value is to define steps in the progressive reduction of air pollution in the most polluted areas. The air quality guideline value (WHO-AQG) is set at 100 μg/m^3.

We first considered a scenario where all daily values above 160 μg/m^3 were reduced to WHO-IT (160 μg/m^3), then a scenario where all daily values above 100 μg/m^3 were reduced to WHO-AQG (100 μg/m^3), and lastly a scenario where the daily mean is decreased by 5 μg/m^3.

The exposure indicator of ozone was the cumulated sum over defined thresholds, calculated using 8hours-daily values.

The corresponding Δx for the two scenarios are;

$$\Delta x = \frac{\sum_{i=1}^{N} O_i}{N}$$

- Scenario 1, if [O3]i≥160 μg/m3, Oi=([O3]i-160)
  if $[O_3]_i$<160 μg/m^3, Oi=0

- Scenario 2, if [O3]i≥100 μg/m3, Oi=([O3]i-100)
  if $[O_3]_i$<100 μg/m^3, Oi=0

- Scenario 3, where the ozone yearly mean is decreased by 5 μg/m3. Δx = 5 μg/m3

PM2.5

For PM2.5, we first considered a scenario where the PM2.5 annual mean is decreased by 5 μg/m^3, and then a scenario where the PM2.5 annual mean is decreased to 10 μg/m^3 (WHO annual AQG).
The exposure indicator of PM2.5 was the yearly mean, calculated as the arithmetic mean of the daily concentrations of the selected stations. The corresponding Δx for the two scenarios are;

- Scenario 1, Δx = 5 μg/m^3

- Scenario 2, Δx = ($[PM2.5]_{mean}$ – 10 μg/m^3)
  Δx = 0 if $[PM2.5]_{mean}$ <10

References

1. Medina S, Tertre AL, Saklad M, on behalf of the Apheis Collaborative Network. The Apheis project: Air Pollution and Health?A European Information System. Air Qual Atmos Health 2009;2:185-498.
2. Ballester F, Medina S, Boldo E, Goodman P, Neuberger M, Iñiguez C, et al. Reducing ambient levels of fine particulates could substantially improve health: a mortality impact assessment for 26 European cities. J Epidemiol Community Health 2008;62(2):98-105.
3. Boldo E, Medina S, LeTertre A, Hurley F, Mücke HG, Ballester F, et al. Apheis: Health impact assessment of long-term exposure to PM(2.5) in 23 European cities. Eur J Epidemiol 2006;21(6):449-58.
4. Anderson HR, Atkinson RW, Peacock JL, Marston L, Konstantinou K. Meta-analysis of time-series studies and panel studies of Particulate Matter (PM) and Ozone (O3). Report of a WHO task group. WHO Regional Office for Europe; 2004.
5. Atkinson RW, Anderson HR, Medina S, Iñiguez C, Forsberg B, Segerstedt B, et al. Analysis of all-age respiratory hospital admissions and particulate air pollution within the Apheis programme. APHEIS Air Pollution and Information System. Health Impact Assessment of Air Pollution and Communication Strategy. Third-year Report. Institut de Veille Sanitaire; 2005. p. 127-33.
6. Gryparis A, Forsberg B, Katsouyanni K, Analitis A, Touloumi G, Schwartz J, et al. Acute effects of ozone on mortality from the "air pollution and health: a European approach" project. Am J Respir Crit Care Med 2004;170(10):1080-7.
7. Pope CA, III, Burnett RT, Thun MJ, Calle EE, Krewski D, Ito K, et al. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. Jama 2002;287(9):1132-41.
8. Pope CA, III, Burnett RT, Thurston GD, Thun MJ, Calle EE, Krewski D, et al. Cardiovascular mortality and long-term exposure to particulate air pollution: epidemiological evidence of general pathophysiological pathways of disease. Circulation 2004;109(1):71-7.

Appendix 2 – Economic valuation

Because the air pollution measures as well as epidemiologic data cover the 2004-2006 period for most of the cities, all costs are consequently expressed in **euros 2005**. Similarly, the average lengths of stay in hospital required for the benefits computations are for 2005.

Valuation of mortality benefits

Regarding mortality, we follow the standard valuation procedure adopted in Cafe (2005), NexExt (2003), ExternE (2000), which consists in **using a Value of a Statistical Life (VSL) and a Value of a Life Year (VOLY) derived from stated preferences surveys**, hence relying on preference-derived values rather than market-derived values. We chose to rely on values obtained in recent European studies (see final Aphekom report for more details).

The choice of the monetary value to assess mortality benefits associated to a decrease in air pollution level depends on the type of impact.

- **For short-term mortality calculations**, the annual number of deaths postponed per year is used. Because the gains in life expectancy corresponding to each of these postponed deaths can be considered in the range of a few months, certainly lower than one year (Cafe 2005, Vol 2, p. 46), a VOLY of €86,600 is applied to each deaths postponed to compute annual benefits.

- **For long-term mortality calculations**, the magnitude of the gain in life expectancy related to the deaths postponed is considered as higher than a year (see Ezzati et al., 2002; Hurley et al. 2005; Watkiss et al. 2005; or Janke et al., 2009). A VSL of €1,655,000 is applied to each deaths postponed to compute annual benefits.

- **For long-term life expectancy calculations**, an average gain in life expectancy for persons 30 years of age is also computed using life tables and following a cohort until complete extinction. The annual corresponding benefits are obtained by multiplying the average gain in life expectancy by the number of 30-year-old individuals in the city, and by the VOLY. This corresponds to the benefits (in terms of life expectancy) 30 year-old people would gain over their lifetime if exposed to the 10 $\mu g/m^3$ average annual level of PM2.5 (WHO's Air Quality Guideline) instead of the current existing air pollution level in the city.

Valuation of hospitalizations benefits

The standard cost of illness approach is used for acute hospitalizations, and consists in applying unit economic values approach to each case, including direct medical and indirect costs.

The direct medical costs related to cardiac and respiratory hospitalizations are computed as the cost per inpatient day times the average length of stay in hospital. These cost data are taken from CEC (2008) for all twelve countries where the cities analysed in Aphekom are located (see Table 12). The average lengths of stay in days are obtained from the OECD Health Database (2010) for all countries except Romania (which is imputed from the population weighted average lengths of the 11 other countries).

The indirect costs are computed as the average gross loss of production per day times twice the average length of stay in hospital. Since we cannot control whether these days were actual working days, we then compute the daily loss of production as the average gross earnings in industry and services (full employment) obtained from Eurostat (2003) for each country, expressed in 2005 and divided by 365 days.

The total medical costs for cardiac and respiratory hospitalizations are obtained by adding together the direct and indirect components.

Table 12: **Average lengths of stay, daily hospitalization costs and work loss, and total hospitalizations cost per patient.**

Country	Average length of stay in days[(a)]		Average cost per day (€ 2005)		Total costs related to hospitalization (€ 2005)	
	Circulatory system	Respiratory system	Hosp. all causes[(b)]	Work loss[(c)]	Circulatory system	Respiratory system
Austria	8.2	6.6	319	83	3,977	3,201
Belgium	9.2	8.8	351	98	5,032	4,814
France	7.1	7.1	366	83	3,777	3,777
Greece	7.0	5.0	389	48	3,395	2,425
Hungary	7.4	6.5	59	18	703	618
Ireland	10.5	6.9	349	81	5,366	3,526
Italy	7.7	8.0	379	62	3,873	4,024
Romania	8.5[(d)]	7.4[(d)]	57	6	587	511
Slovenia	8.6	7.3	240	34	2,649	2,248
Spain	8.5	7.4	321	55	3,664	3,189
Sweden	6	5.2	427	92	3,666	3,177
United Kingdom	11.4	8.0	581	116	9,268	6,504
Mean[(d)]	**8.5**	**7.4**	**373**	**73**	**4,411**	**3,840**

Sources: [(a)] OECD Health Data (2010); [(b)] CEC (2008), annex 7, cost/bed/day corr; [(c)] Eurostat (2003); [(d)] population-weighted average, 2005 population data from OECD Health Data (2010).

For instance, based on Table 12, the average direct cost of a cardiac hospital admission is:

8.5 days x € 373= € 3,171

and the corresponding indirect cost related to work loss is:

2 x 8.5 days x € 73= € 1,241.

Overall, the unit economic value related to a cardiac hospital admission is € 4,412.

For city-specific valuation, the last two columns of Table 12 provide average hospitalization costs computed following the same rationale but using country-specific average lengths of stay, cost per day of hospitalization and daily work loss.

Valuation of the benefits of EU legislation to reduce the sulphur content of fuels

The legislation has two potential effects on mortality: short-term and long-term. It has been decided that, to take a conservative standpoint, mortality effects will be considered as short-term effects. Consequently, a VOLY of €86,600 is applied to each premature deaths to compute the benefits of the legislation. The economic evaluation thus constitutes a lower bound of the mortality benefits of the legislation.

References

Ezzati, M., Lopez, A., Rodgers, A., van der Hoorn, S., Murray, C.J.L. and the Comparative Risk Assessment Collaborating Group. (2002), Selected major risk factors and global and regional burden of disease. The Lancet, 360, 1347-1360.

Hurley, F., Cowie, H., Hunt, A., Holland, M., Miller, B., Pye, S. and Watkiss, P. (2005), Methodology for the Cost-Benefit analysis for CAFE, Volume 2: Health Impact Assessment.

Janke K., Propper C., and Henderson J. (2009). Do current levels of air pollution kill? The impact of air pollution on population mortality in England. Health Economics, doi:10.1002/hec.1475.

Watkiss, P., S. Pye and Holland M. (2005), CAFE CBA: Baseline Analysis 2000 to 2020 Service Contract for Carrying out Cost-Benefit Analysis of Air Quality Related Issues, in particular in the Clean Air for Europe (CAFE). Programme AEAT/ED51014/Baseline Scenarios; issue 5, AEA Technology, April, 122 p.

The Aphekom collaborative network

The authors would like to thank the Aphekom collaborative network for its invaluable contribution to the project, in particular:

▪ French Institute for Public Health Surveillance, InVS, Saint-Maurice, France – Sylvia Medina, Kanwal Eshai, Christophe Declercq, Agnès Lefranc, Myriam Blanchard, Sophie Larrieu, Tek-Ang Lim, Alain Le Tertre, Laurence Pascal, Mathilde Pascal, Magali Corso, Aymeric Ung.

▪ Umeå University, Umeå, Sweden – Bertil Forsberg, Lars Modig, Kadri Meister, Hans Orru

▪ Medical University of Vienna, Austria – Hanns Moshammer, Manfred Neuberger, Daniela Haluza, Hans-Peter Hutter

▪ Barcelona Public Health Agency, Spain – Manuel Nebot, Anna Perez, Natalia Valero

▪ Centre for Research in Environmental Epidemiology, CREAL, Barcelona, Spain, Swiss Tropical and Public Health Institute and University of Basel, Basel, Switzerland – Nino Künzli, Laura Perez-Grau, Xavier Basagaña, David Agis Cherta

▪ Dublin Institute of Technology, Ireland – Patrick Goodman, Susann Henschel

▪ St. George's, University of London, United Kingdom – Richard Atkinson

▪ Department of Hygiene, Epidemiology and Medical Statistics, Medical School, University of Athens, Greece – Klea Katsouyanni, Antonis Analitis, Konstantina Dimakopoulou, Alexandros Gryparis, Eva Kougea, Xanthi Pedeli

▪ Centre of Economics and Ethics for the Environment and Development, C3ED, University of Versailles Saint-Quentin-en-Yvelines, UVSQ, France – Yorghos Remvikos, Delphine Delalande, Jeroen Van der Sluijs, Martin O'Connor

▪ Valencian School for Health Studies, EVES, and Centre for Research on Public Health, CSISP, Valencia, Spain – Ferran Ballester, Carmen Iñiguez, Marisa Estarlich

▪ Brussels Institute for the Management of the Environment, Belgium – Catherine Bouland

▪ Basque Foundation for Health Innovation and Research, Vitoria-Gasteiz, Spain – Teresa Martínez-Rueda, Koldo Cambra, Eva Alonso, Sausan Malla, Francisco Cirarda

▪ Andalusian School of Public Health, EASP, Granada, Spain – Antonio Daponte, Piedad Martin-Olmedo, Alejandro Lopez-Ruiz, Marina Lacasaña, Pablo Sánchez-Villegas

▪ National Institute of Public Health, Bucharest, Romania – Emilia Maria Niciu, Bogdan Constantin Stolica, Ioana Pertache

▪ Institute of Public Health of the Republic of Slovenia, Ljubljana, Slovenia – Peter Otorepec, Katarina Bitenc, Ana Hojs

▪ National Institute of Environmental Health, Budapest, Hungary – Anna Páldy, János Bobvos, Gizella Nador

▪ Rome E Health Authority, Italy – Francesco Forastiere, Giulia Cesaroni, Chiara Badaloni

The Aphekom Scientific Committee

▪ University of Bath, United Kingdom – Alistair Hunt

▪ Institute of Occupational Medicine, Edinburgh, United Kingdom – Brian Miller, Fintan Hurley

▪ WHO European Centre for Environment & Health, Bonn, Germany – Michal Krzyzanowski

▪ WHO European Centre for Environment & Health, Rome, Italy – Martin Krayer Von Krauss

▪ European Commission DG Joint Research Centre, Ispra, Italy – Peter Pärt

▪ Spanish National Research Council, CSIC, Barcelona, Spain – Xavier Querol

▪ Mailman School of Public Health, Columbia University, New York, United States of America – Patrick Kinney

Other Aphekom contributors

- BRUNEL UNIVERSITY, London, United Kingdom – Ariana Zeka
- NATIONAL CENTER FOR SCIENTIFIC RESEARCH, GREQAM AND IDEP, Marseille, France – Olivier Chanel
- REGIONAL HEALTH OBSERVATORY OF THE PARIS ILE-DE-FRANCE REGION, ORS, Paris, France – Sabine Host, Edouard Chatignoux
- SAKLAD CONSULTANTS FOR COMMUNICATIONS STRATEGY, Paris & New York – Michael Saklad
- STOCKHOLM ENVIRONMENT ADMINISTRATION – Christer Johansson and Boel Lövenheim
- WWAM WRITERS LTD., Birmingham, United Kingdom – Geoff Davies

Coordination

- FRENCH INSTITUTE FOR PUBLIC HEALTH SURVEILLANCE, InVS, France - Sylvia Medina
- UMEA UNIVERSITY, SWEDEN - Bertil Forsberg

Funding and support

The Aphekom project has been co-funded by the European Commission's Programme on Community Action in the Field of Public Health (2003-2008) under Grant Agreement No. 2007105, and by the many national and local institutions that have dedicated resources to the fulfilment of this project.

To learn more

www.aphekom.org