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

Local city report

Lyon

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Summary

The Psas program (www.invs.sante.fr/surveillance/psas9/), which monitors air pollution and health in France, has contributed to the health impact assessments (HIA) of urban air pollution carried out in 25 European cities by the Aphekom project (Improving Knowledge and Communication for Decision Making on Air Pollution and Health in Europe, www.aphekom.org). Institut de Veille Sanitaire (InVS) has coordinated both projects.

Because informing decision-making at the city level remains a core focus of both projects, we have broken the HIAs out for each participating city to highlight its local specificities.

We chose various scenarios for reducing exposure to particulate matter and ozone and we used different tools and exposure/response functions to estimate the short and long term health impacts of the different pollutants. Below appears the HIA findings for the city of Lyon.

The specific HIA for Lyon found that a significant health gain would be achieved by lowering annual mean levels of PM in Lyon. The compliance with the WHO-AQG for PM10 (20µg/m^3) would induce a moderate benefit on mortality and hospital admissions (18 deaths and 64 hospital admissions and avoided per year). The associated monetary gain would be of more than 1.8 millions €.

Lowering PM2.5 would have a higher impact. Compliance with the WHO-AQG of 10 µg/m^3 would postpone 246 deaths, corresponding to a gain in life expectancy of 0.5 years per inhabitant. This gain in life expectancy would be valued at more than 600 millions €.

The results from the present health impact assessment (HIA) may help promoting measures aiming at reducing air pollutant emissions, especially from traffic.

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 also 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 Lyon, 60 deaths per year could be avoided by reducing PM2.5 levels by 3.5 µg/m^3. This corresponded to a gain in life expectancy of 60 years cumulated for the whole population. Reducing PM10 levels to 20 µg/m^3 would avoid 19 deaths. Enhis project further found that reducing PM10 daily mean values to 20 µg/m^3 would prevent 7 hospital respiratory admissions of children under 15 years old. Each reduction by 10 µg/m^3 of the daily maximum 8-hour moving average ozone concentrations would delay 8 deaths per year in the general population in the study area, 4 from cardiovascular diseases, and 2 from respiratory causes. In terms of hospital admissions, this would represent 1 respiratory admission in the adult (15-64 years old) population and 5 respiratory admissions in the population over 64 years.

Building on the experience gained in the Apheis project, 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.

This work shows that a decrease to 10 µg/m^3 of long-term exposure to PM2.5 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 PM2.5.

Hence, exceeding the WHO air-quality guideline on PM2.5 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.

This report details the results for Lyon.

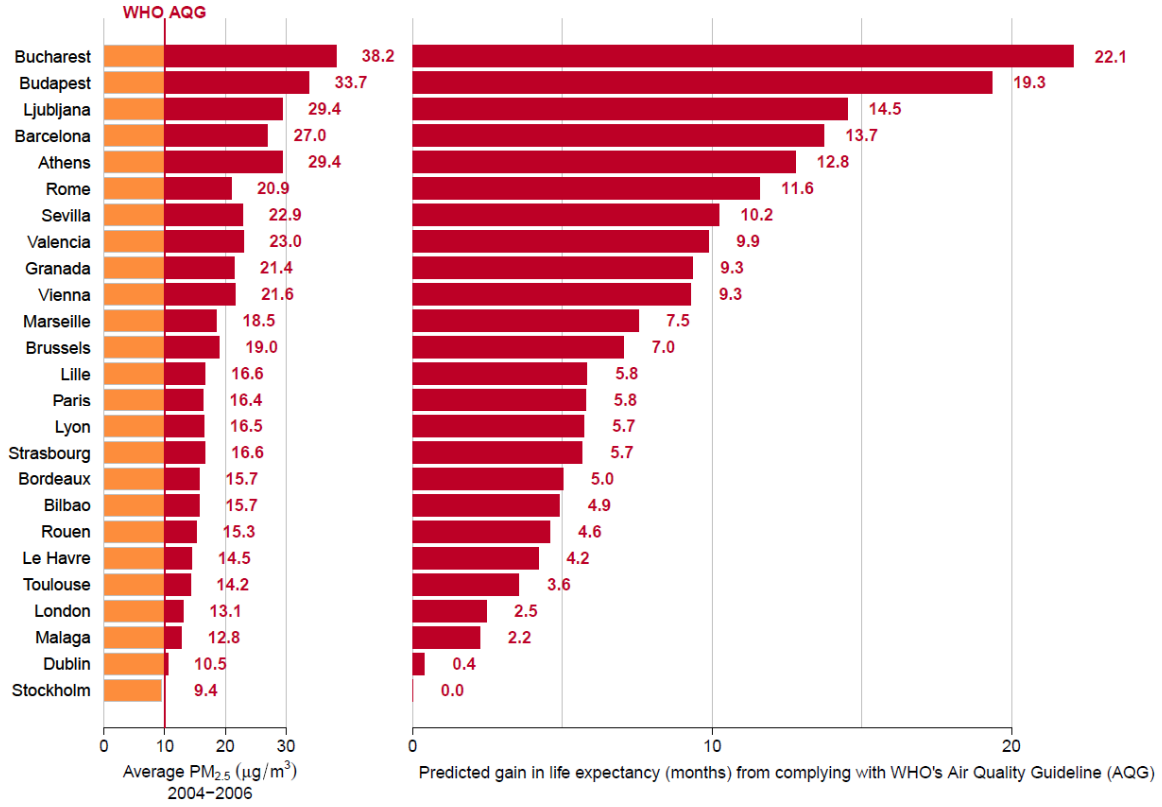


Figure 1 – **Predicted average gain in life expectancy (months) for persons 30 years of age in 25 Aphekom cities for a decrease in average annual level of PM2.5 to 10 $µg/m^3$ (WHO's Air Quality Guideline)**

1.1. Description of the study area for Lyon

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 includes 18 municipalities around Lyon. The metropolitan area of Lyon is localized in the Rhone Valley. It is a main river, railway and road crossing area.

Climatology

A continental climate with anticyclonic conditions of temperature inversion in winter is commonly encountered in the study area. Daily mean temperatures range from 8℃ in winter to 17℃ in summer. The colder months were January, February and March for the year 2002, with respectively 16, 1 and 2 days below 0℃. Conversely, June, July and August were the warmest months with respectively 14, 12 and 15 days above 25℃. The minimum relative humidity is 52%. Rainy months were essentially May, August and November with respectively 13, 13 and 19 days of rainfall above 0.5 mm. Wind speed greater than 3 $m.s^{-1}$ occurred at least 5 days per month in February, March, September, October and December.

Population in the study area

The study area includes 18 municipalities around Lyon with 1 012 715 inhabitants (14.8% of whom are more than 65 years) spread out on 230 km² of land (density of 4 403 inhab./km²).

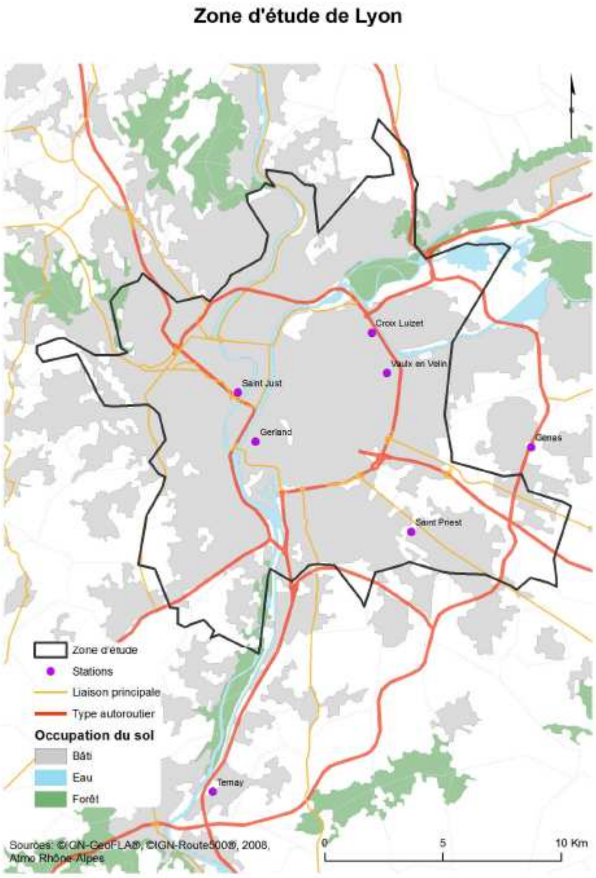


Figure 2 – Map of the study area

Commuting

Lyon city counts every day 4 400 000 moves on average. This number increases by 25% every 10 years. In 1999, an average of 600 000 vehicles penetrated Lyon each day, among them 100 00 and 90 000 cross the Fourvière and Croix-Rousse tunnels respectively. 200,000 come from both the South and North express roads. This influx is explained by the fact that the study area employs about 400 000 people, 60% of whom do not live within it.

1.2. Sources of air pollution and exposure data

Sources

Road traffic represents 66% of the emissions of nitrogen oxides followed by industrial activities (18%). The distribution of the emissions by sources is more balanced for PM10; industrial activities represent 36% of the emissions, whereas residential/tertiary activities reach 23% and road traffic and other mobile sources 19%. Seventy percent of sulphur emissions come from industries (mainly the Feyzin refinery in the Rhone valley).

Table 1 – Main sources of air pollution (% t/year)(Data for the year 2006 and the 58 municipalities of the urban area of Lyon, source Coparly)

Pollutant	Transportation (road, planes, trains)	Residential/tertiary sector	Industry/waste management	Other sources (energy, farming…)
SO_2	1%	10%	89%	
NO_x	68%	9%	23%	1%
Primary PM_{10}	34%	15%	50%	1%
Primary $PM_{2.5}$	37%	21%	41%	1%

Exposure data

Data concerning air pollution levels were obtained from Coparly, the local air pollution monitoring network.

All the background stations within study area were used to build the exposure indicators for the period 2004-2006. Four urban stations were used Saint Just (O3), Gerland (O3), Croix-Luizet (O3), Vaux-en-Velin (O3, PM10, PM2.5), and a suburban station was used for ozone (Saint-Priest).

Ozone concentrations are measured by Ultraviolet photometric method. PM10 and PM2.5 concentrations are measured by quartz microbalance method (TEOM).

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): 1.22
- 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 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 WHO limit value (20µg/m^3). The daily maximum 8-hour moving average has been higher than 100µg/m^3 during 207 days between 2004 and 2006, and above 160µg/m^3 during 9 days

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

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

Pollutant	Mean (µg/m^3)	Standard deviation (µg/m^3)	*5th percentile* (µg/m^3)	*95th percentile* (µg/m^3)
Ozone (daily 8h max)	68	36	12	127
Corrected PM10 (daily average)	25	14	11	51
Corrected PM2.5 (daily average)	16	11	6	38

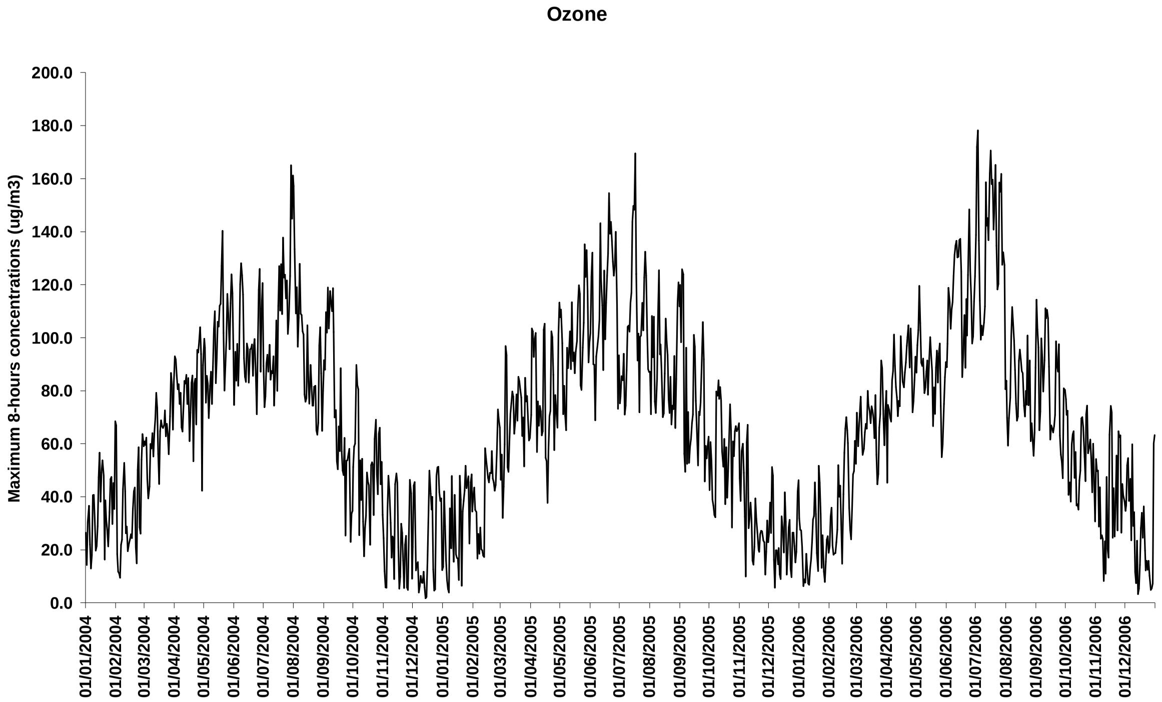


Figure 3 – Ozone concentration in the study area

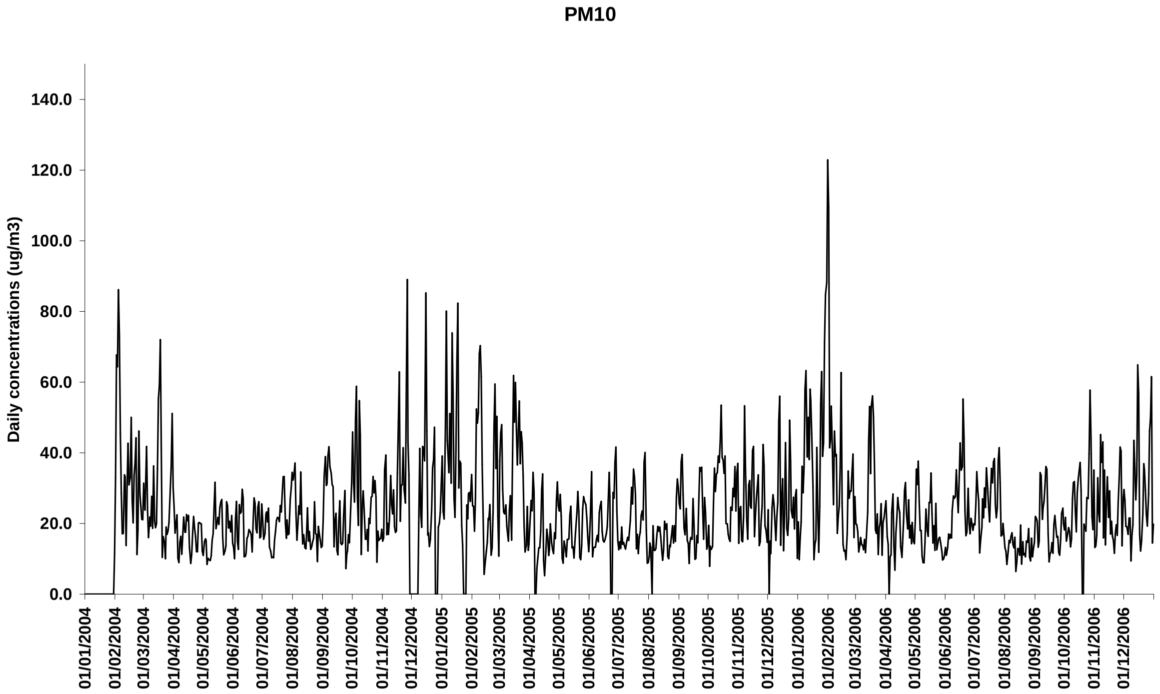


Figure 4 – PM10 concentration in the study area

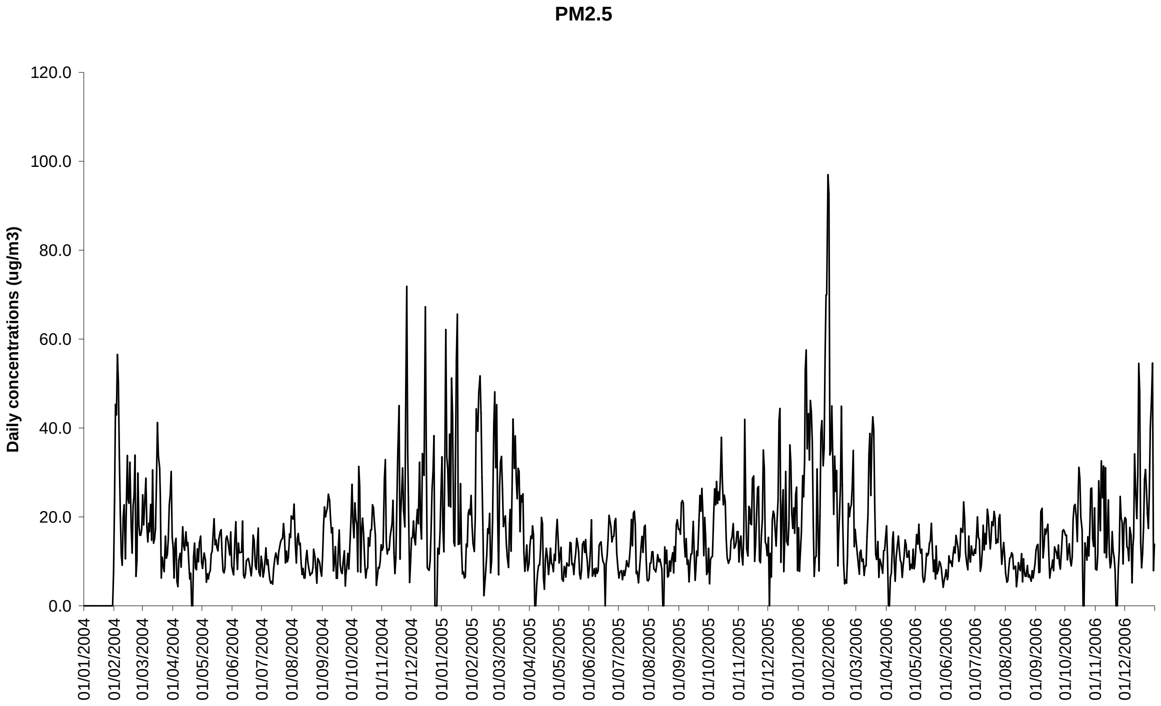


Figure 5 – PM2.5 concentration in the study area

1.3. Health data

The number of deaths in the general population (non-external mortality) was 6534 (annual rate 645 per 100,000), among which 1838 (annual rate 317 per 100,000) were due to cardiovascular causes.

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

Health outcome	ICD9	ICD10	Age	Annual mean number	Annual rate per 100 000
Non-external mortality*	< 800	A00-R99	All	6534	645
Total (including external) mortality	000-999	A00-Y98	> 30	6687	1155
Cardiovascular mortality	390-429	I00-I52	> 30	1838	317
Cardiac hospitalisations	390-429	I00-I52	All	8601	849
Respiratory hospitalisations	460-519	J00-J99	All	7543	745
Respiratory hospitalisations	460-519	J00-J99	15-64 yrs	2622	259
Respiratory hospitalisations	460-519	J00-J99	≥ 65 yrs	3035	300

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

1.4. Health impact assessment

Aphekom uses 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.

Here we present a summary of our HIA method.

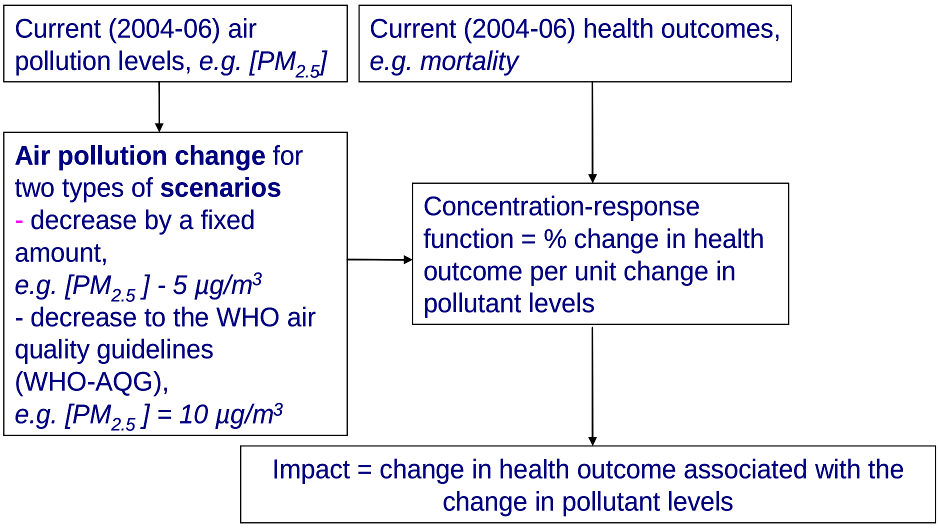


Figure 6 – Principles of local health impact assessment (HIA)

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 20 deaths per year, 43 hospitalisations for respiratory diseases and 26 hospitalisations for cardiac diseases. Decreasing the annual mean to 20 µg/m^3 would postpone 18 deaths per year, 40 hospitalisations for respiratory diseases and 24 hospitalisations 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	20	2
Decrease to 20 µg/m^3	18	2

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

Table 5 — Potential benefits of reducing annual PM10 levels on hospitalisations

	Respiratory hospitalisations		Cardiac hospitalisations	
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	43	4	26	3
Decrease to 20 µg/m^3	40	4	24	2

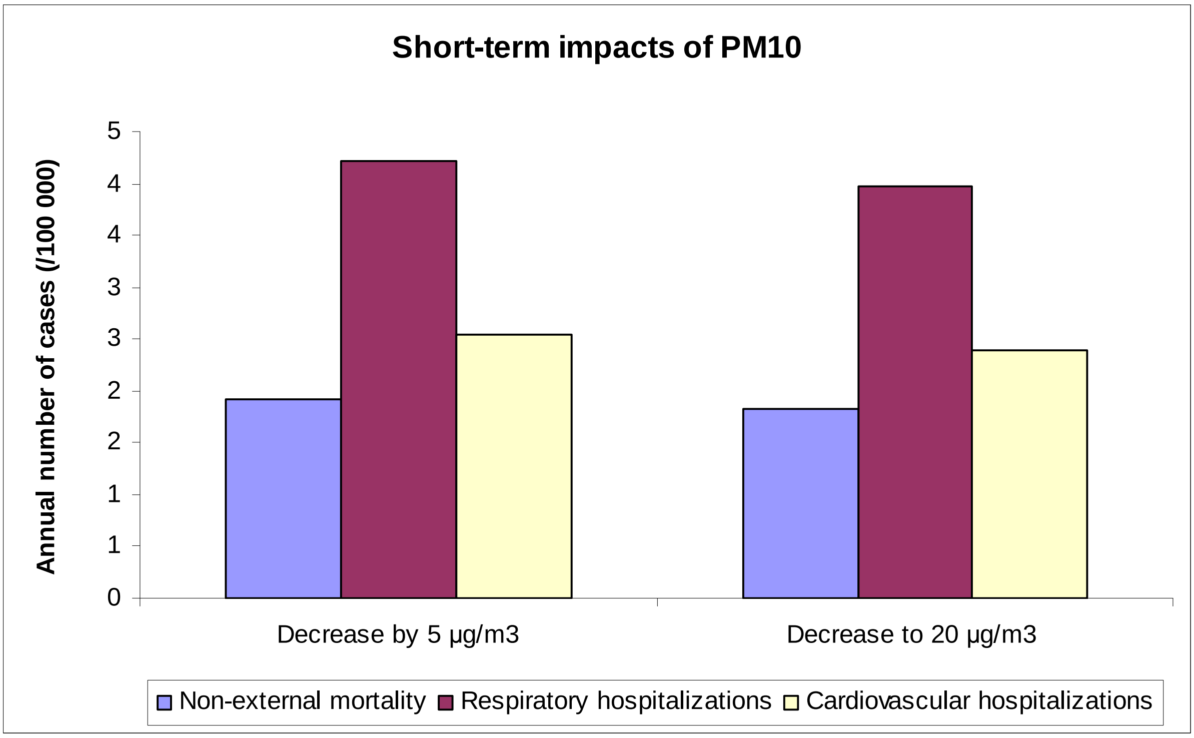


Figure 7 — Potential benefits of reducing annual PM10 levels on mortality and on hospitalisations

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. 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 during the study period except for nine days Decreasing values above 100 µg/m^3 to 100 µg/m^3 would postpone 8 deaths, 1 hospitalisation for respiratory diseases for people aged 15 to 64, and 6 hospitalisations for respiratory diseases for people older than 65.
Decreasing all concentrations by 5 µg/m^3 would postpone 10 deaths, 1 hospitalisation for respiratory diseases for people aged 15 to 64, and 8 hospitalisations 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	0.1	0.01
8h max daily values >100 µg/m^3 = 100 µg/m^3	8	1
Decrease by 5 µg/m^3	10	1

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

Table 7 ─ Potential benefits of reducing daily ozone levels on hospitalisations

	Respiratory hospitalisations (15-64)		Respiratory hospitalisations (>64)	
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
8h max daily values >160 µg/m^3 = 160 µg/m^3	0.02	0.00	0.09	0.06
8h max daily values >100 µg/m^3 = 100 µg/m^3	1	0.15	6	4
Decrease by 5 µg/m^3	1	0.19	8	5

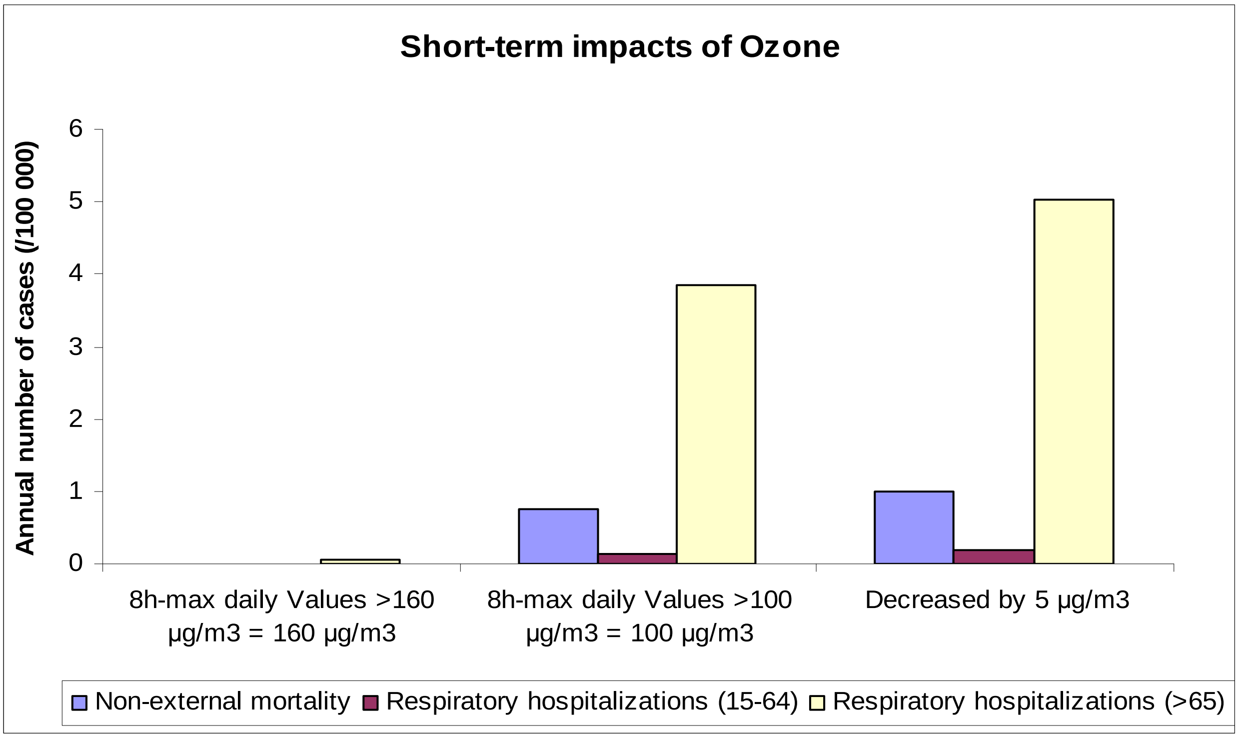


Figure 8 ─ Potential benefits of reducing daily ozone levels on mortality and on hospitalisations

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 192 deaths, and 101 deaths for cardiovascular causes. This corresponds to a gain in life expectancy of 0.4 years per inhabitant.

Decreasing concentrations to 10 µg/m^3 would postpone 246 deaths, and 129 deaths for cardiovascular causes. This corresponds to a gain in life expectancy of 0.5 years per inhabitant.

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

Scenarios	Total annual number of deaths postponed	Annual number of deaths postponed per 100 000	Gain in life expectancy
Decrease by 5 µg/m^3	192	33	0.4
Decrease to 10 µg/m^3	246	42	0.5

* 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
Decrease by 5 µg/m^3	101	17
Decrease to 10 µg/m^3	129	22

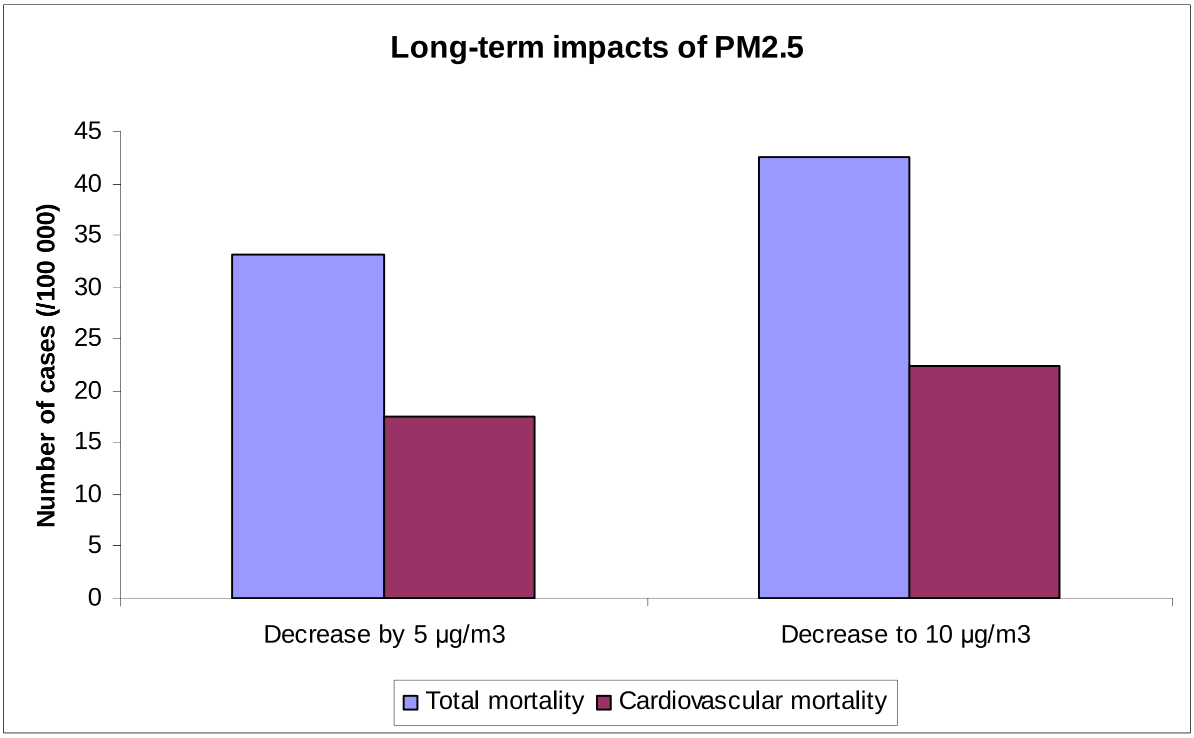


Figure 9 – Potential benefits of reducing annual PM2.5 levels on mortality

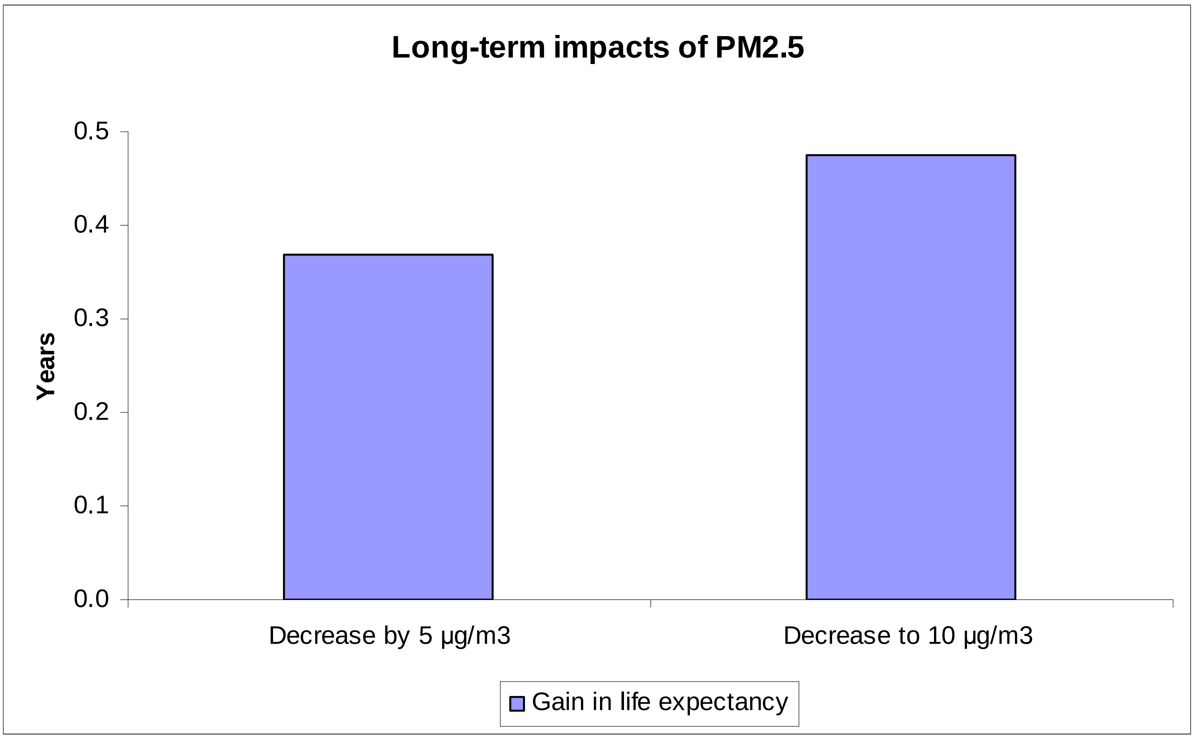


Figure 10 – Potential benefits of reducing annual PM2.5 levels on life expectancy

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 hospitalisations.

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. Indeed, the short- and long-term postponed deaths differ regarding the size of the gains in life expectancy (see Appendix 2).

For short-term impacts, the monetary value of €86,600 was chosen. Decreasing PM10 concentration by 5 µg/m^3 would then correspond to a saving of 17 320 000€. Decreasing PM10 concentrations to 20 µg/m^3 would correspond to a saving of 1 558 800€. Decreasing ozone concentrations above 100 µg/m^3 to 100 µg/m^3 would save 692 800€.

For long-term impacts, the monetary value of € 1,655,000 was chosen. Decreasing PM2.5 concentrations by 5 µg/m^3 would then correspond to a saving of 167,155,000€. Decreasing PM2.5 concentrations to 10 µg/m^3 would correspond to a saving of 213,495,000€. Taking into account the gain in life expectancy would correspond to a saving of 541,513,264€ for the first scenario, and 676,891,580€ for the second.

Hospitalisations

The standard cost of illness approach is used for short-term hospitalisations, 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 hospitalisation costs 3 777€, the savings would be of 260,613€ when reducing PM10 concentrations by 5 µg/m^3 and of 241,728€ 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 26,439€.

1.4.5. Interpretation of findings

A significant health gain would be achieved by lowering the PM concentrations in Lyon. The compliance with the WHO-AQG for PM10 (20µg/m^3) would induce a moderate benefit on mortality and hospital admissions (18 deaths and 64 hospital admissions avoided per year). The associated monetary gain would be of more than 1.8 millions €.

Lowering PM2.5 would have a greater impact. Compliance with the WHO-AQG of 10 µg/m^3 would postpone 246 deaths, corresponding to a gain in life expectancy of 0.5 years per inhabitant. This gain in life expectancy would be valued more than 600 millions €.

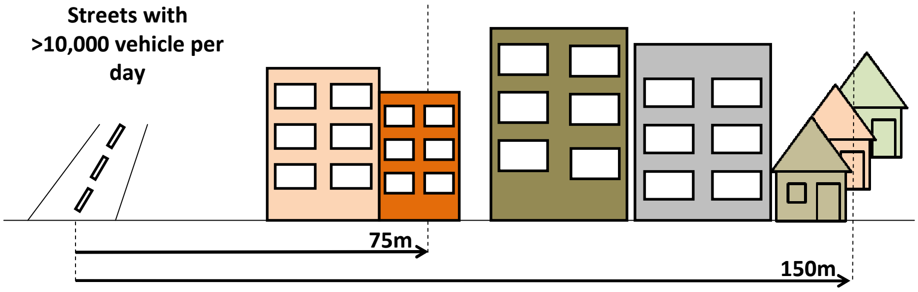
The results from the present HIAs may help promoting measures aiming at reducing air pollutant emissions, especially traffic-linked emissions.

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.

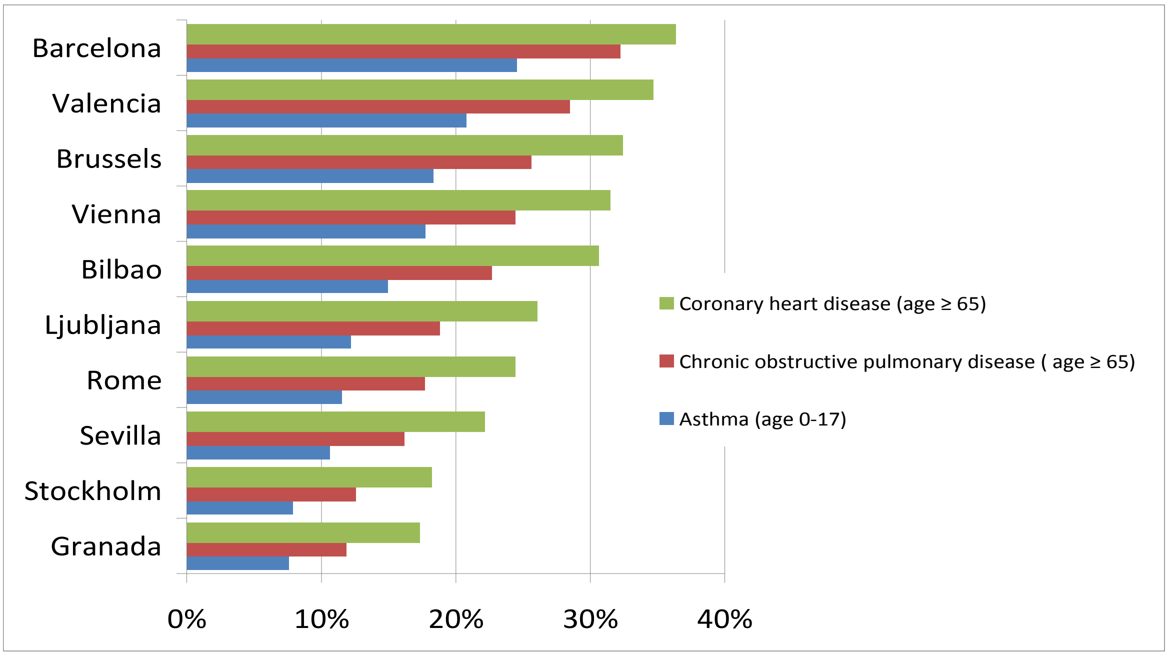


Figure 12 ─ Percentage of population with chronic diseases whose disease is attributable to living near busy streets and roads in 10 Aphekom cities

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.

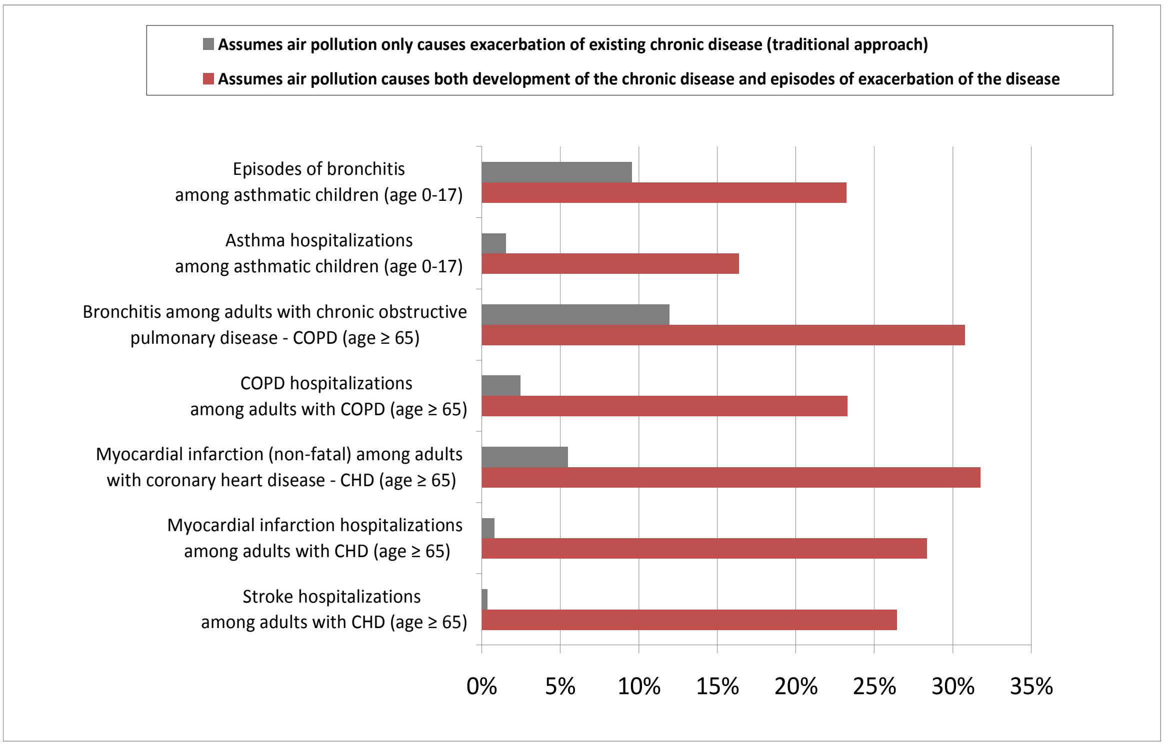


Figure 13 ─ Comparison of impact of air pollution on chronic diseases calculated using two different HIA approaches in Aphekom

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 project 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 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.

Overall, for 20 European cities involved in the Aphekom project, this analysis showed not only a marked, sustained reduction in ambient SO_2 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 SO_2 in the cities studied 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) SO_2 concentrations that has been observed across all centres (except the French centres excluding Lyon) over the time period of the study is illustrated in Figure 14. Overall there was no clear step change in SO_2 concentrations after implementation of the Directives; rather a gradual decline in SO_2 levels was observed.

Furthermore city specific observations for Lyon of are presented in Figure 15 showing seasonal averages of UB SO_2 (please note change in scaling compared to Fig. 14).

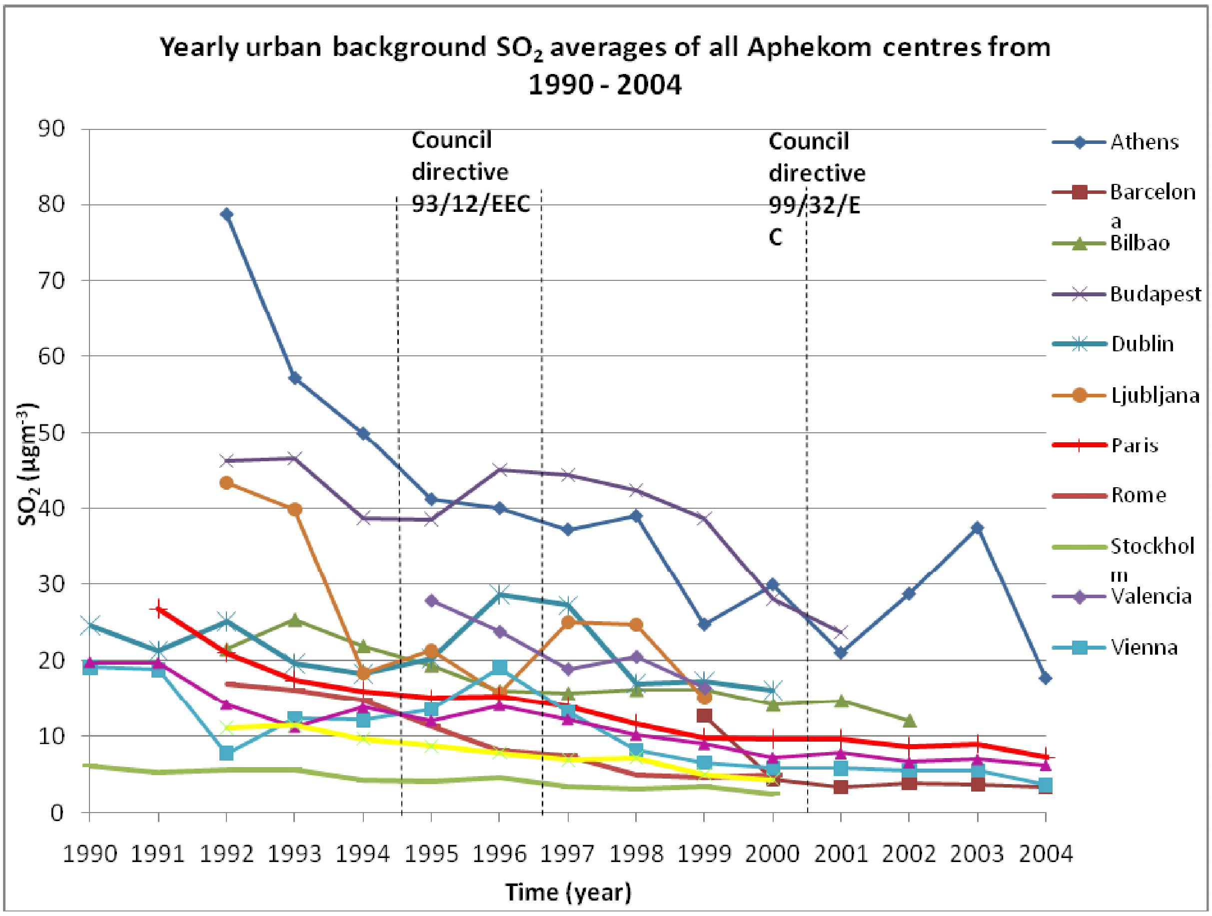


Figure 14 – Plot of yearly urban background SO_2 averages of all Aphekom centres from 1990 – 2004

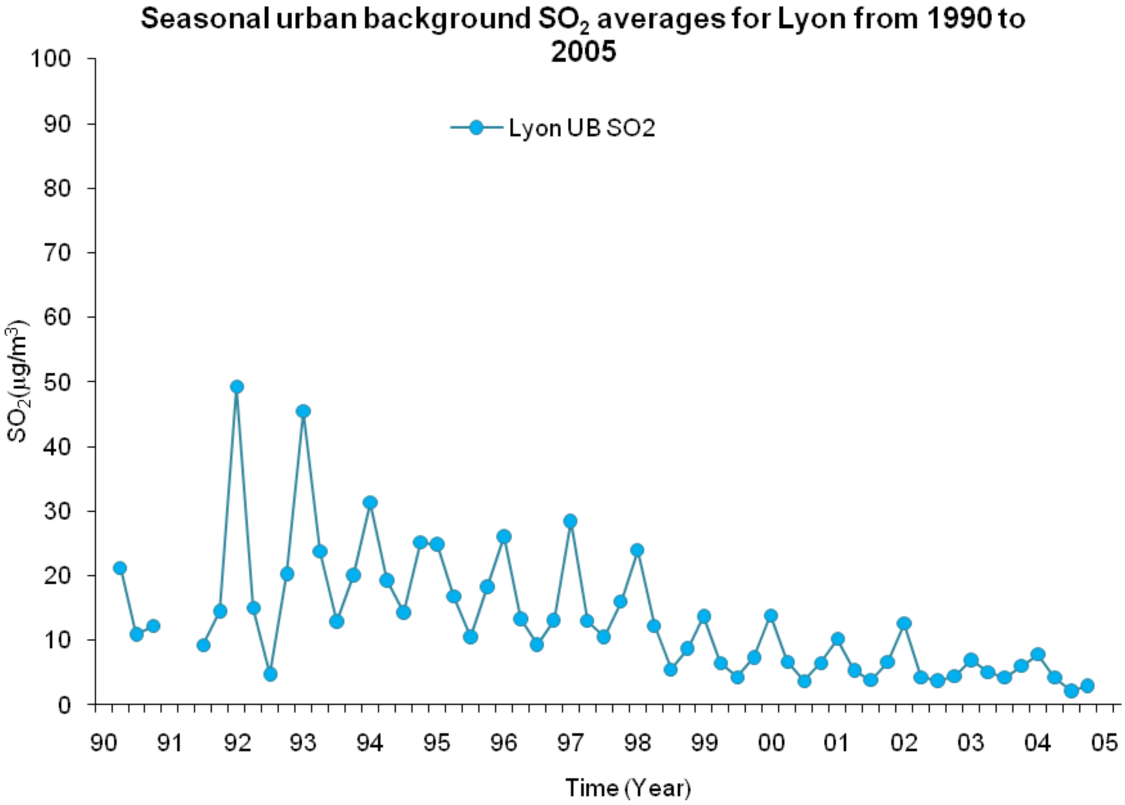


Figure 15 – Plot of seasonal urban background SO_2 averages for Lyon from 1990 – 2001

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. Lyon observed peaks frrom winter 1992 to 1998 with higher levels in 92 and 93..

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.

For these 14 cities, 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 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 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 Lyon, the implementation of:

- the first stage in 1994 reduced annual deaths by 17 deaths from all causes, by 1 death from respiratory and by 8 deaths from cardiovascular causes compared to the baseline period prior to October 1994 with no directive being implemented.

- the 2nd stage in 1996 reduced annual deaths by 37 deaths from all causes, by 3 deaths from respiratory and by 29 deaths from cardiovascular causes compared to the baseline period with no directive being implemented.

- the 3rd stage in 2000 reduced annual deaths by 62 deaths from all causes, by 4 deaths from respiratory and by 29 deaths from cardiovascular causes compared to the baseline period with no directive being implemented.

As a result on a city specific level for Lyon (summarized in Table 10) 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 Lyon 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	cases per year	95% CI	cases per year	95% CI
Stage 1 [≥ 01.10.1994 and <01.10.1996]	17	6 - 27	1	0 - 3	8	2 - 13
Stage 2 [≥ 01.10.1996 and <01.07.2000]	37	13 - 60	3	-1 - 6	17	5 - 29
Stage 3 [≥ 01.07.2000]	62	22 - 103	4	-1 - 10	29	9 - 50

Section 4. Sharing Knowledge and Uncertainties with Stakeholders

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 involved in developing policy options. 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.

This type of multi-criteria assessment enables highlighting divergences of opinion, focusing discussions on critical points and bridging differences among stakeholders from differing backgrounds. As a result, this process facilitates both communication and decision making.

To test use of the process and tool, Aphekom conducted two case studies in Brussels and in Paris during the development of local air-quality action plans. The case studies demonstrated the ability of the method and tools to structure discussions and highlight differing views, as confirmed by participants' satisfaction with their use.

We also developed an online tool to familiarize users with the deliberation-support process used in the case studies and to enable them to create their own deliberative forums http://aphekom.kertechno.net/.

Section 5. Overview of findings and local recommendations

The specific HIA for Lyon found that a significant health gain would be achieved by lowering annual mean levels of PM. The compliance with the WHO-AQG for PM10 (20µg/m^3) would induce a moderate benefit on mortality and hospital admissions (19 deaths and 64 hospital admissions and avoided per year). The associated monetary gain would be of more than 1.8 millions €.

Lowering PM2.5 would have a higher impact. Compliance with the WHO-AQG of 10 µg/m^3 would postpone 246 deaths, corresponding to a gain in life expectancy of 0.5 years per inhabitant. This gain in life expectancy would be valued at more than 600 millions €.

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.

In France, a plan to reduce air pollution must be implemented in all cities over 250 000 inhabitants (PPA: plan de protection de l'atmosphère, according to the law on air and the rational use of energy of the 30th December 1996). An update of this plan will be realised for Lyon with the objectives of complying with the French regulation in 2015. Lyon will also be a pilot zone for the implementation of policies to reduce air pollution (Zone d'Actions Prioritaires pour l'Air (ZAPA)). The results from the present HIA should help promoting measures aiming at reducing air pollutant emissions within this plan.

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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 ($\beta=\log(\text{RR per } 10\ \mu g/m^3)/10$)

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 1).

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 hospitalisations	All	1.0114 [1.0062-1.0167]	(5)
	Cardiac hospitalisations	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 hospitalisations	15-64	1.001 [0.991-1.012]	(4)
	Respiratory hospitalisations	>=65	1.005 [0.998-1.012]	(4)
Long-term impacts of PM2.5	Total 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/m^3. Δx = 5 µg/m^3

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. Indeed, the approach most widely used to value mortality elicits a hypothetical willingness to pay to benefit from a small decrease in mortality risk. Based on this trade-off, it then computes a VSL (used for long-term mortality effects) and/or a VOLY (used for short- and long-term mortality effects). 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 hospitalisations benefits

The standard cost of illness approach is used for acute hospitalisations, 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 hospitalisations 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 1). 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 hospitalisations are obtained by adding together the direct and indirect components.

Table 12 – Average lengths of stay, daily hospitalisation costs and work loss, and total hospitalisations cost per patient.

Country	Average length of stay in days^(a)^		Average cost per day (€ 2005)		Total costs related to hospitalisation (€ 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 1, 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 1 provide average hospitalisation costs computed following the same rationale but using country-specific average lengths of stay, cost per day of hospitalisation 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.

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