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

Local city report

Barcelona

Public Health Agency of Barcelona

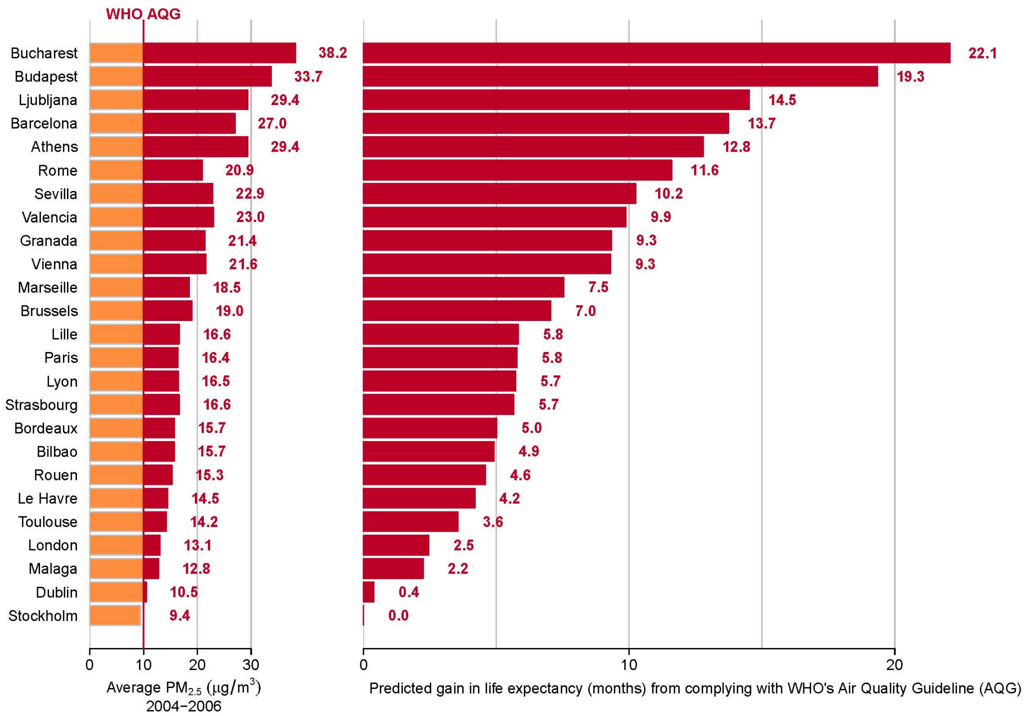
Summary

The Aphekom study was a multi-centre project funded by the European Commission (Grant Agreement: 2007105) with the aim of calculating, using standardised statistical techniques, the benefit to human health of reductions in air pollution. The project comprised investigators from 25 European cities including Barcelona. Data on mortality and hospital admissions in Barcelona from 2004 to 2006 were used to assess potential benefits of reductions in PM_{10}, fine particles ($PM_{2.5}$) and ozone under a number of scenarios. The results for Barcelona must to be interpreted with caution because the number of monitoring stations and their representativity of the citizens exposition would to be discussed. The average annual level for PM10 belongs from two monitoring stations and for PM2.5 and ozone the data belongs from only one monitoring station. Considering the compliance of the European legislative values during the study period, the annual mean value of PM10 did not exceed the limit value (40 µg/m^3) and ozone values did not reached in any day the information threshold (180 µg/m^3).

Achieving a scenario in the city of Barcelona with all days with PM10 levels under 20 µg/m^3 would postponed 10 deaths per 100,000 inhabitants, 22 respiratory hospitalisations per 100,000 inhabitants and 9 cardiac hospitalisations per 100,000 inhabitants. Each reduction by 5 µg/m^3 of the daily mean of ozone would postponed 2 deaths per 100,000 inhabitants and 9 cardiac hospitalisations per 100,000 inhabitants in persons 64 years of age or older. Achieving a scenario with all days with PM2.5 levels under 10 µg/m^3 would postponed 130 deaths per 100,000 inhabitants, 79 cardiovascular deaths per 100,000 inhabitants and a gain of life expectancy of 1.1 years.

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. The results for $PM_{2.5}$ are summarised in the figure below. The comparison between cities would be interpreted with caution because health outcome definition, population characteristics (age distribution, other risk factors) and the number and location of the monitoring sites or the analytical methods used could vary between cities.

Predicted average gain in life expectancy (months) for persons 30 years of age and older in 25 Aphekom cities for a decrease in average annual level of PM2.5 to 10 µg/m3 (WHO's Air Quality Guideline)



Acronyms

APHEIS: Air Pollution and Heath, a European Information System (www.apheis.org)

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

HIA: health impact assessment

O3 : ozone

PM_{10} : particulate matter with an aerodynamic diameter <10 µm

$PM_{2.5}$: particulate matter with an aerodynamic diameter <2.5 µm

PM: Particulate Matter (generic term for particles irrespective of size)

VOLY: Value of Life Year

WHO: World Health Organision

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.

Chapter 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.

Barcelona HIA results in the preceding Apheis project highlighted that achieving a scenario with all days with black smoke mean levels under 20 $\mu g/m^3$ would postponed 84 deaths (5.5 per 100,000 inhabitants), 19 cardiovascular deaths (1.3 per 100,000 inhabitants) and 10 respiratory deaths (0.7 per 100,000 inhabitants).

Enhis1 results showed that each reduction by 10 $\mu g/m^3$ of the daily maximum 8-hour moving average concentrations in Barcelona would delay 22 deaths (1.5 per 100,000 inhabitants), 11 from cardiovascular diseases (0.7 per 100,000 inhabitants), and 9 from respiratory causes (0.6 per 100,000 inhabitants). In terms of hospital admissions, this would represent 1 respiratory admissions (0.1 per 100,000 inhabitants) in the adult population (15 to 64 years) and 21 respiratory admissions (6 per 100,000 inhabitants) in the population over 64 years.

In 2007, the Centre of Research in Environmental Epidemiology (CREAL) published a HIA for the Barcelona metropolitan area and found that reducing current levels of air pollution to the WHO standards would result in about 3,500 fewer annual deaths (about 12% of all deaths among people 30 years and older) (4).

Building on the experience gained in the earlier 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 and older.

This work shows that a decrease to 10 micrograms/cubic metre 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 $PM_{2.5}$.

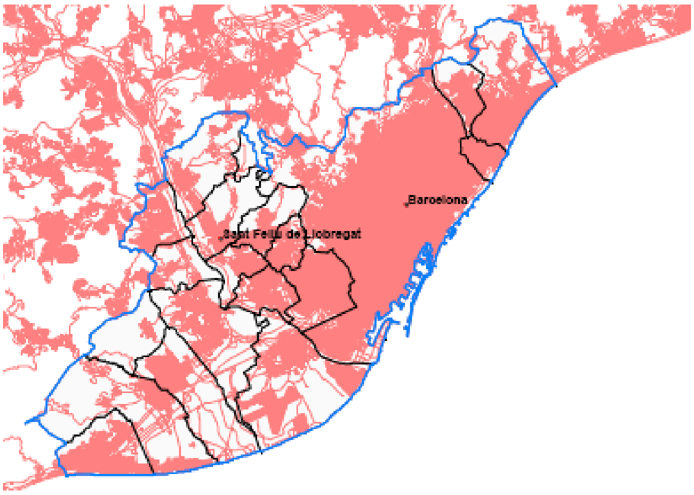
Hence, exceeding the WHO air-quality guideline on $PM_{2.5}$ leads to a burden on mortality of nearly 19,000 deaths per annum, more than 15,000 of which are caused by cardiovascular diseases.

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.

1.1. Description of the study area for Barcelona

The study area is the city of Barcelona. Located on the western shore of the Mediterranean Sea, Barcelona is bordered by the Collserola mountain range to the north, the river Besos to the east and the river Llobregat to the west. These topographical limits and the availability of air pollution data were the main reasons to define the study area. The city of Barcelona and 18 more municipalities are included in the Air Quality Zone 1: Barcelona Area.

Figure 1 – Map of the study area and situation of Barcelona in the Air Quality Zone 1: Barcelona Area (5)



Climatology

Barcelona has a Mediterranean climate. The annual mean value of temperature for the period 2004-2006 was 16.4ºC, the minimum was 12.5ºC and the maximum was 20.3ºC. For the same period, average of daily relative humidity was 66.3% and total rainfall was 540.5 mm/year (source:http://www.bcn.cat).

Population in the study area

The surface area of Barcelona is 100.8 km^2. The population of Barcelona in 2008 was 1,615,908, of whom 47.5% were men and 52.5% were women. There has been a significant increase in foreign residents over the last 25 years: in 2008 they represented 17.9% of the population while back in 1996 they made up just 2. Another major change is the increase in the number of people who live alone: 11.9% in 2008, rising from just 6.4% in 1991. In 2008, the proportion of people aged 85 or more living alone was 40.9% women and 20.7% men (6).

1.2. Sources of air pollution and exposure data

Sources

Although an specific inventory emissions is not available for the study area, some results shown that traffic contributes in 40% of the total emissions of nitrogen oxides (NO_X) and 52% of the total emissions of PM_{10} in the whole “Air Quality Zone 1: Barcelona Area”(6). The main sources has not changed since the last Apheis/Enhis1 findings.

Table 1 – Main sources of air pollution in “Air Quality Zone 1: Barcelona Area” (expressed tons/year; reference year: 2004) (7)

Pollutant	Industry	Energy	Road transport	Marine transport	Air transport	Housing
NO_x	10,508	2,938	13,493	3,007	2,171	1,791
PM_{10} *	851	232	1,538	252		129

* PM10 road transport inventory emissions includes combustion emissions, erosion of brakes, erosion of pneumatics, erosion of road surface and resuspension of the ground in asphalted roads.

Exposure data

Three background monitoring stations were selected to define exposure indicators (Table 2). For PM10, two background monitoring stations were selected and for PM2.5 and ozone the data belongs to only one monitoring station.

Table 2 – Monitoring stations selected for the HIA

	Monitoring stations	Measurement method	Data provider	Percentage of valid data (2004-2006)
PM10	**Zona Universitaria**	gravimetric EU reference method	Division of Environmental Surveillance of the Public Health Agency of Barcelona	61%
	Jaume Almera Institute	laser-spectrometer corrected with gravimetric EU reference method	Institute of Earth Sciences Jaume Almera; Institute of Environmental Assessment and Water Research	95%
PM2.5	**Jaume Almera Institute**	laser-spectrometer corrected with gravimetric EU reference method	Institute of Earth Sciences Jaume Almera; Institute of Environmental Assessment and Water Research	95%
Ozone	**Ciutadella**	UV absorption	Division of Environmental Surveillance of the Public Health Agency of Barcelona	79%

The annual mean level (SD) of PM10 in Barcelona was 37 (16) µg/m^3, and P5 and P95 of the daily mean values were respectively, 17 µg/m^3 and 64 µg/m^3. The annual mean level (SD) of PM2.5 was 27 (13) µg/m^3, and P5 and P95 of the daily mean values were respectively, 12 µg/m^3 and 51 µg/m^3. The mean (SD), P5 and P95 of the daily maximum 8-hour moving average concentrations of ozone were respectively, 57(27), 14 and 102 µg/m^3 (Table 3 and Figures 2, 3 and 4).

The annual mean value of PM10 did not exceed the European limit value (40 µg/m^3) and ozone values did not reached in any day the information threshold (180 µg/m^3).

Table 3 – 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)	57	27	14	102
PM10 (daily average)	37	16	17	64
PM2.5 (daily average)	27	13	12	51

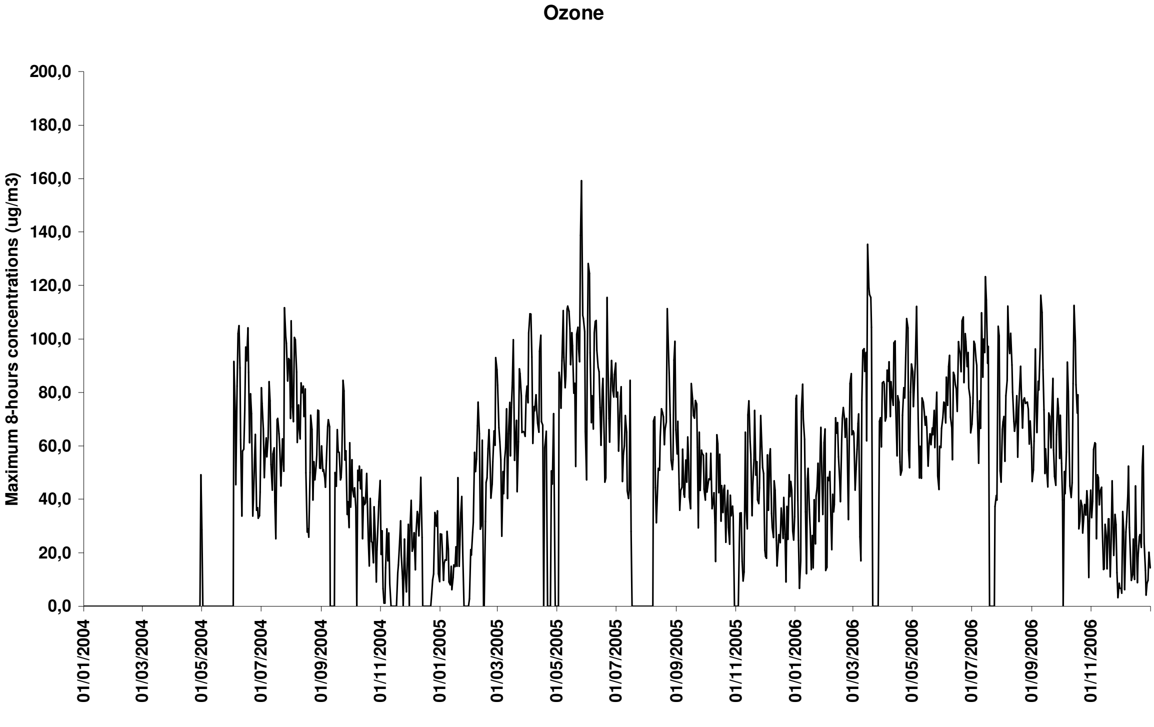


Figure 2 – Ozone concentration in Barcelona (2004-2006)

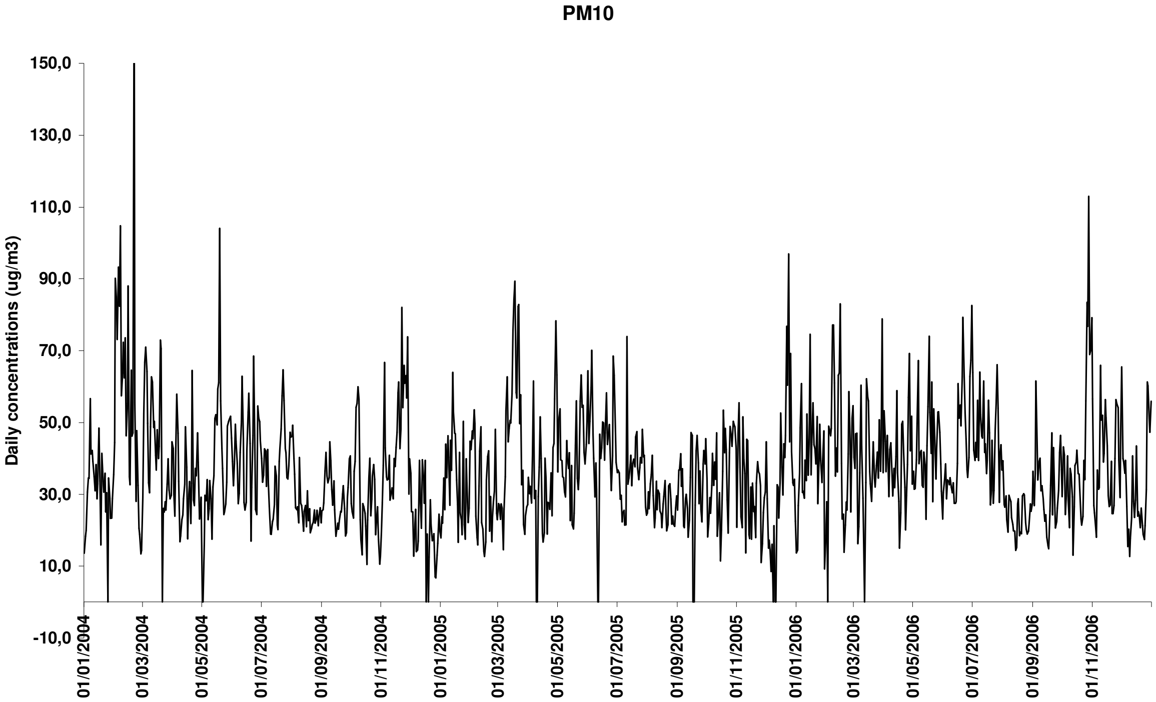


Figure 3 – PM10 concentration in Barcelona (2004-2006)

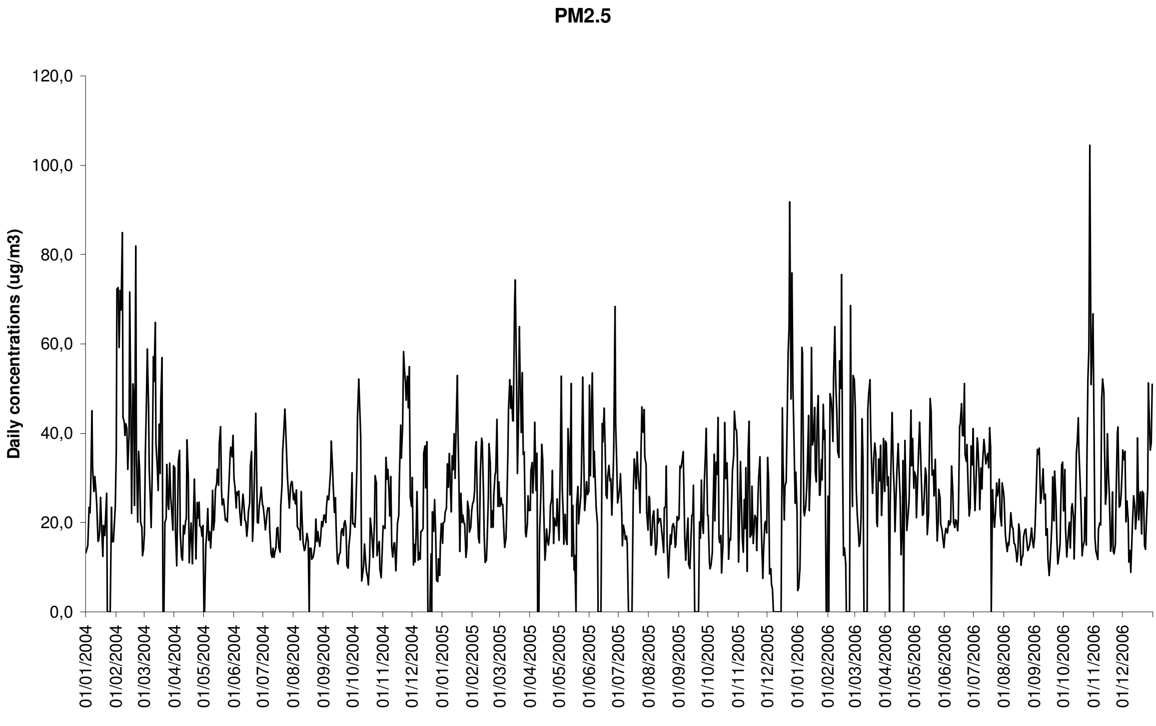


Figure 4 – PM2.5 concentration in Barcelona (2004-2006)

1.3. Health data

An annual mean number of 15,355 deaths* occurred in Barcelona. In people 30 years and older the annual number of deaths was 15,244. Regarding hospital admissions 14,244 annual cardiac hospitalisations and 18,350 annual respiratory hospitalisations has been registered. Respiratory hospitalisations were higher in people with more than 65 years. Mortality data were provided by the Health Observatory in the Public Health Agency of Barcelona. Hospital admissions data were provided by the “Consorci Sanitari de Barcelona”. For the HIA only deaths and emergency admissions of residents in Barcelona have been selected.

Table 4 – Annual mean number and annual rate per 100 000 deaths and hospitalizations (2004-2006)

Health outcome	ICD9	ICD10	Age	Annual mean number	Annual rate per 100 000
Non-external mortality*	< 800	A00-R99	All	15,355	964
Non-external mortality	< 800	A00-R99	> 30	15,244	1,378
Cardiovascular mortality	390-429	I00-I52	> 30	4,986	451
Cardiac hospitalizations	390-429	I00-I52	All	14,244	894
Respiratory hospitalizations	460-519	J00-J99	All	18,350	1,152
Respiratory hospitalizations	460-519	J00-J99	15-64 yrs	5,139	323
Respiratory hospitalizations	460-519	J00-J99	≥ 65 yrs	11,487	721

*** 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.

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 $\mu g/m^3$, and then a scenario where the PM10 annual mean is decreased to 20 $\mu g/m^3$, the WHO annual air quality guideline (WHO-AQG).

Each reduction by 5 $\mu g/m^3$ of the annual mean of PM10 would postponed 46 deaths (3 deaths per 100,000 inhabitants), 104 respiratory hospitalisations (7 cases per 100,000 inhabitants) and 43 cardiac hospitalisations (3 cases per 100,000 inhabitants).

Achieving a scenario with all days with PM10 levels under 20 $\mu g/m^3$ would postponed 157 deaths (10 deaths per 100,000 inhabitants), 353 respiratory hospitalisations (22 cases per 100,000 inhabitants) and 145 cardiac hospitalisations (9 cases per 100,000 inhabitants).

Table 5 — 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	46	3
Decrease to 20 µg/m^3	157	10

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

Table 2 — 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	104	7	43	3
Decrease to 20 µg/m^3	353	22	145	9

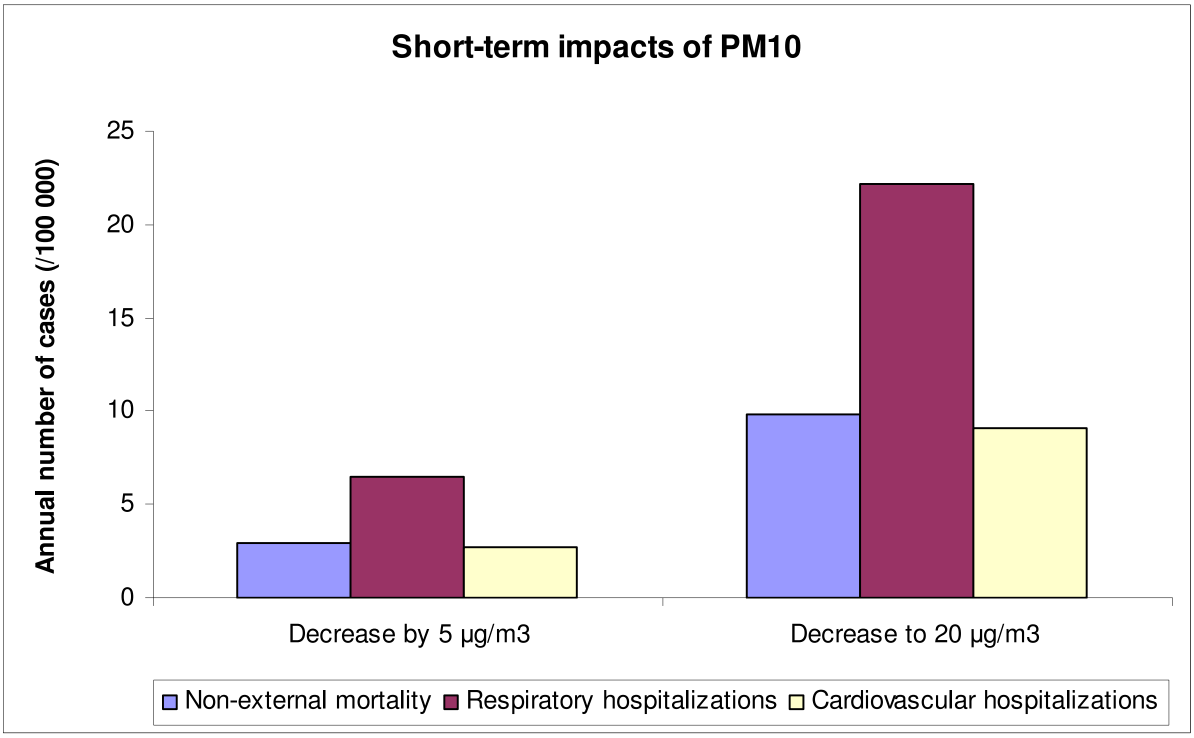


Figure 5 — Potential benefits of reducing annual PM10 levels on mortality and on hospitalisations

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.

Achieving a scenario with all 8h max daily values of ozone under 100 µg/m^3 would postponed 5 cardiac hospitalisations in people >64 years (1 case per 100,000 inhabitants). Each reduction by 5 µg/m^3 of the daily mean of ozone would postponed 24 deaths (2 deaths per 100,000 inhabitants) and 29 cardiac hospitalisations in people >64 years (9 cases per 100,000 inhabitants).

Ozone daily data for the year 2004 were not included in the HIA because the percentage of daily data was lower than 75%.

Table 3 – 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	4	0
Decrease by 5 µg/m^3	24	2

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

Table 4 – Potential benefits of reducing daily ozone levels on hospitalizations

	Respiratory hospitalizations (15-64)		Cardiac hospitalizations (>64)	
Scenarios	**Total annual number of cases potsponed**	**Annual number of cases potsponed per 100 000**	**Total annual number of cases potsponed**	**Annual number of cases potsponed per 100 000**
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	0	5	1
Decrease by 5 µg/m^3	3	0	29	9

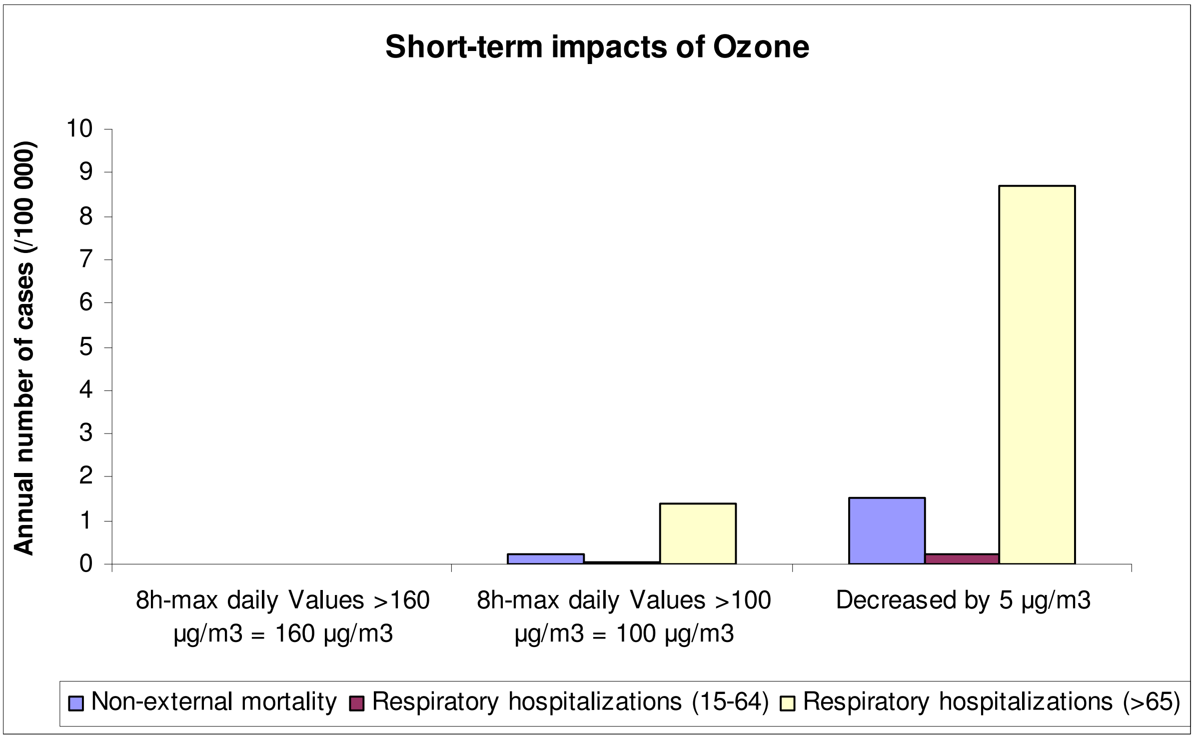


Figure 6 — Potential benefits of reducing daily ozone levels on mortality and on hospitalisations

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).

Each reduction by 5 µg/m^3 of the annual mean of PM2.5 would postponed 438 deaths (40 deaths per 100,000 inhabitants) and 275 cardiovascular deaths (25 deaths per 100,000 inhabitants) and a gain of life expectancy of 0.3 years.

Achieving a scenario with all days with PM2.5 levels under 10 µg/m^3 would postponed 1,437 deaths (130 deaths per 100,000 inhabitants) and 874 cardiovascular deaths (79 deaths per 100,000 inhabitants) and a gain of life expectancy of 1.1 years.

Table 5 – 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	438	40	0.3
Decrease to 10 µg/m^3	1437	130	1.1

Table 6 – Potential benefits of reducing annual PM2.5 levels on total cardiovascular mortality

Scenarios	Total annual number of deaths posponed	Annual number of deaths postponed per 100 000
Decrease by 5 µg/m^3	275	25
Decrease to 10 µg/m^3	874	79

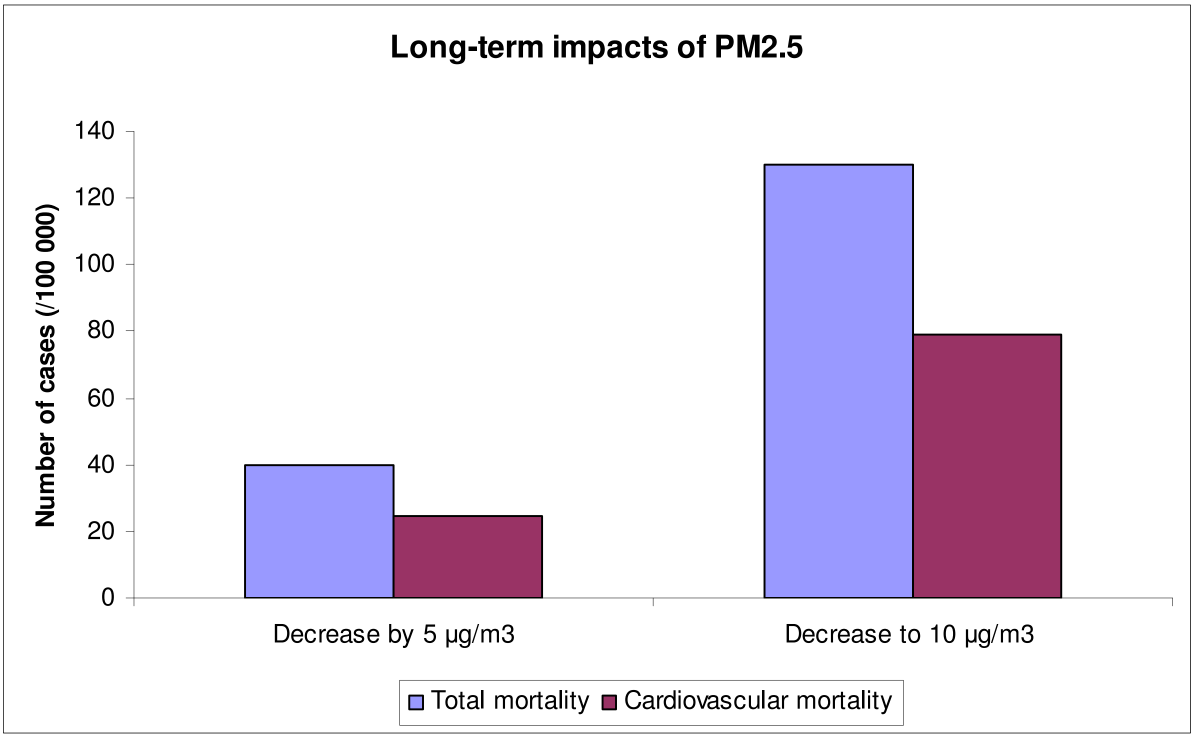


Figure 7 — Potential benefits of reducing annual PM2.5 levels on mortality

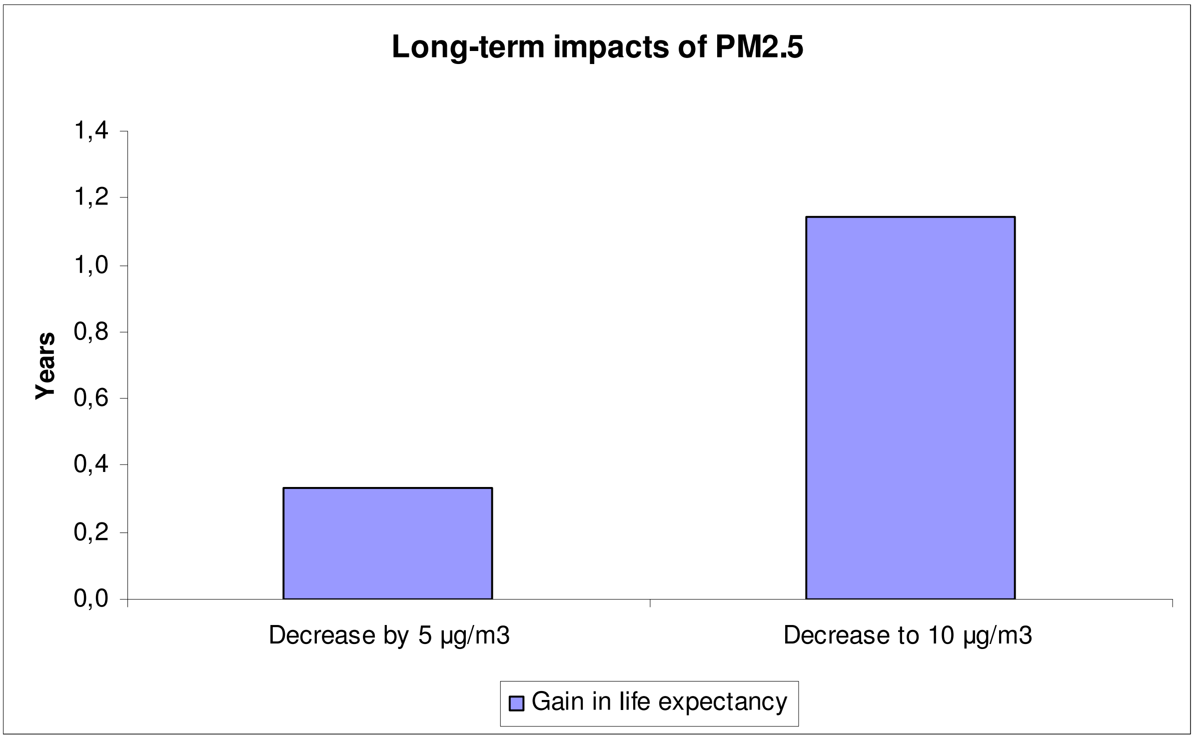


Figure 8 — Potential benefits of reducing annual PM2.5 levels on life expectancy

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 (see Appendix 2).

For short-term impacts, the monetary value of €86,600 should be applied to the total annual number of deaths postponed.

For long-term impacts, the monetary value of € 1,655,000 should be applied to the total annual number of deaths postponed in your city.

The way gain in life expectancy should be estimated is detailed in Appendix 2.

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.

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 unit economic values will differ across cities, based on specific local market prices for medical resources and wages (see Appendix 2). The economic benefits related to a reduction in air pollution exposure are then computed by multiplying the number of hospitalisations in your city by the corresponding unit economic value.

1.4.5. Interpretation of findings

In this report the APHEKOM team have derived estimates of the health impact of both short- and long-term exposure to particles and ozone. These impacts have been estimated as the numbers of deaths and admissions attributable to air pollution avoided under different reduction scenarios.

HIA assumes a causal relationship between exposure to air pollution and the health outcome under consideration based on the scientific relationships argued in the literature. HIA comparison between cities must to be interpreted with caution because health outcome definition and population characteristics like age distribution and other risk factors could vary between cities.

HIA findings depend on the measured levels of air pollution. These levels vary widely as a function of the number and location of the monitoring sites and the analytical methods used. Although all the cities followed some criteria to select the monitoring stations, the comparability of data would to be discussed.

Chapter 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.

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Figure 9 — 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.

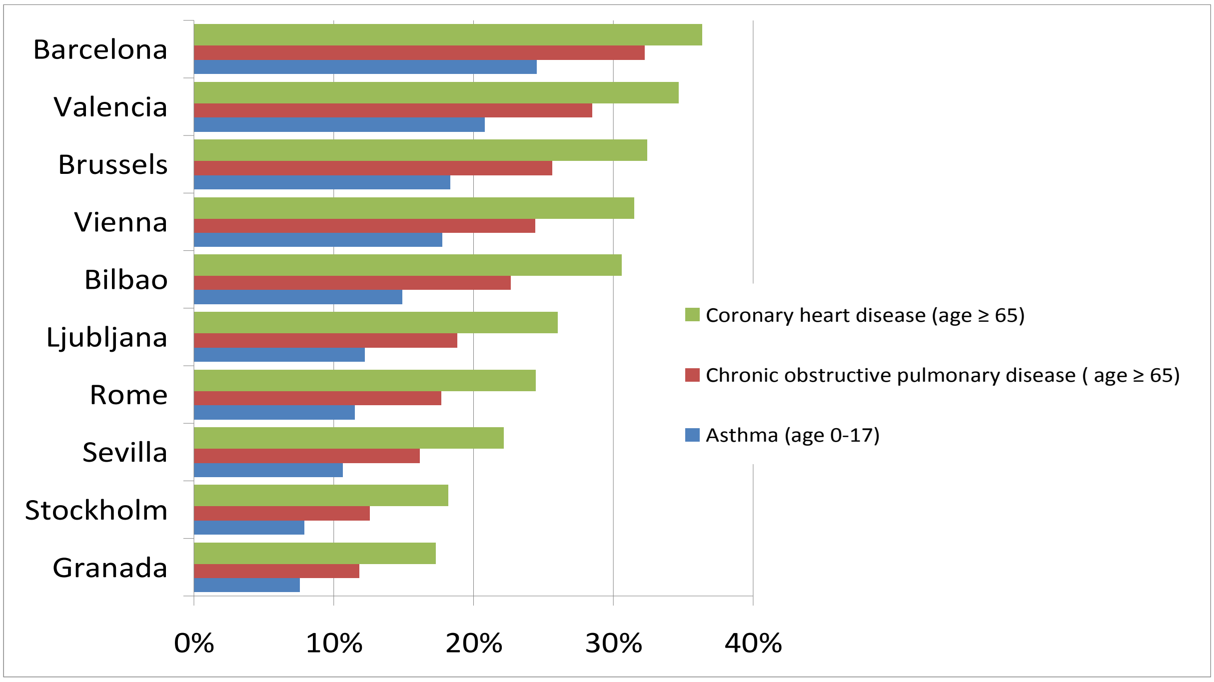

Figure 10 — Percentage of population with chronic diseases whose disease is attributable to living near busy streets and roads in 10 Aphekom cities

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.

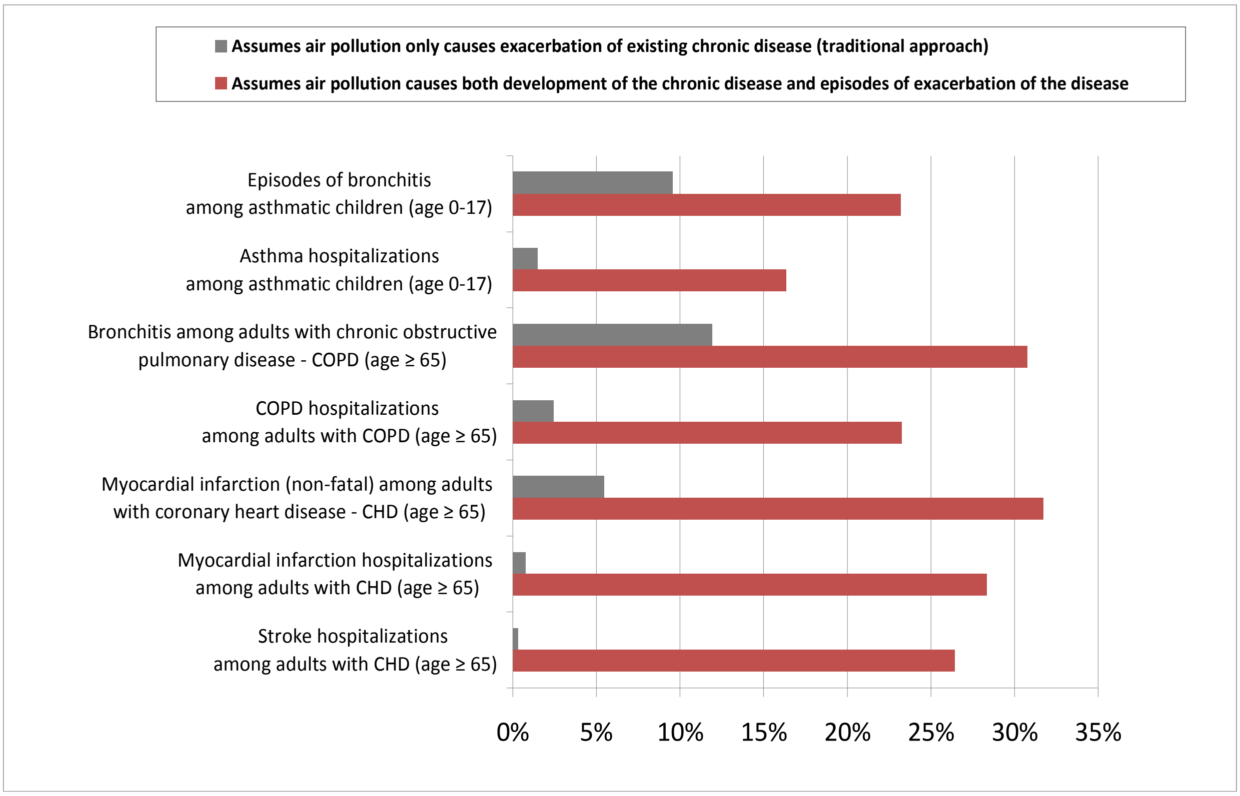

Figure 11 – Comparison of impact of air pollution on chronic diseases calculated using two different HIA approaches in Aphekom

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.

Chapter 3. Health Impacts of Implemented Policies in Air Pollution

Beyond reviewing the documented benefits to health of the historic Dublin coal ban in 1990 and the recent implementation of congestion charges in London and Stockholm, 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).

Our analysis in 20 cities showed 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.

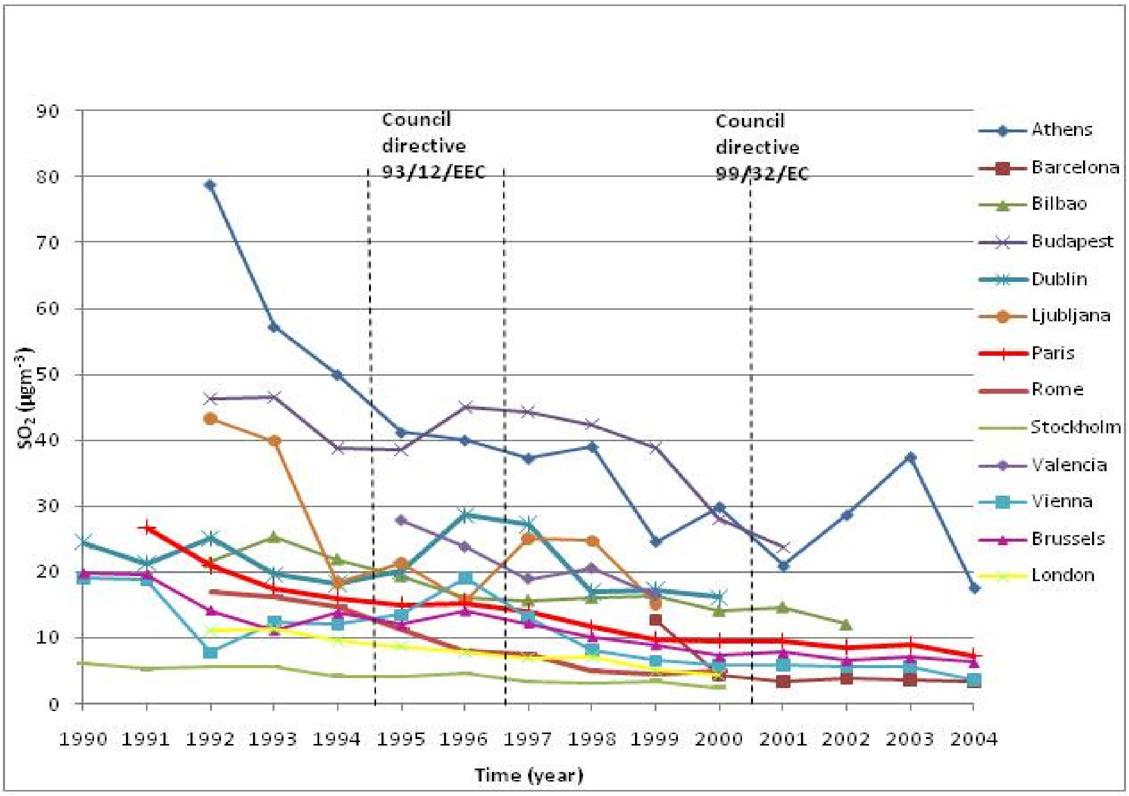

Figure 12 — Yearly urban background SO_2 averages for 13 Aphekom cities from 1990 to 2004

Figures 13 and Figure 14 show preliminary work done using hourly SO2 data from Vienna, Austria showing seasonal plots for winter (Fig.13) and summer (Fig 14) for a central urban station for the years 1990 to 2000. For example: In Figure 13 SO2 levels are showing a general decreasing trend over time. The two peaks observed consistently throughout all years between 6am and noon and as well between 4pm and 11pm for the winter plots (Fig. 13) suggest that those peaks are mainly caused by traffic due to the morning and evening rush hours and as well due to space heating especially in the evenings. Comparing the two seasons the summer plot (Fig. 14) shows a clear reduction in peak SO2 levels for the afore mentioned time periods. This might indicate the proportion of SO2 that resulted from emissions due to heating during the winter months especially as high SO2 levels are observed for a few consecutive hours from ~5pm up to midnight coinciding with inversion. The smaller peaks are still observed again coinciding with the morning and evening rush hours and also reflecting climatic effects.

In Fig. 13 the observed winter SO2 levels for the central urban station in Vienna in 1990 are markedly higher than later years and even though if the peak patterns look like in the other years the observed high SO2 levels do not necessarily have to be caused by traffic. It is not clear, if these high SO2 values were reached due to high sulphur content in diesel fuel for vehicles or due to other sources, such as fuel oil combustion, heating, being emitted simultaneously with the traffic related emissions.

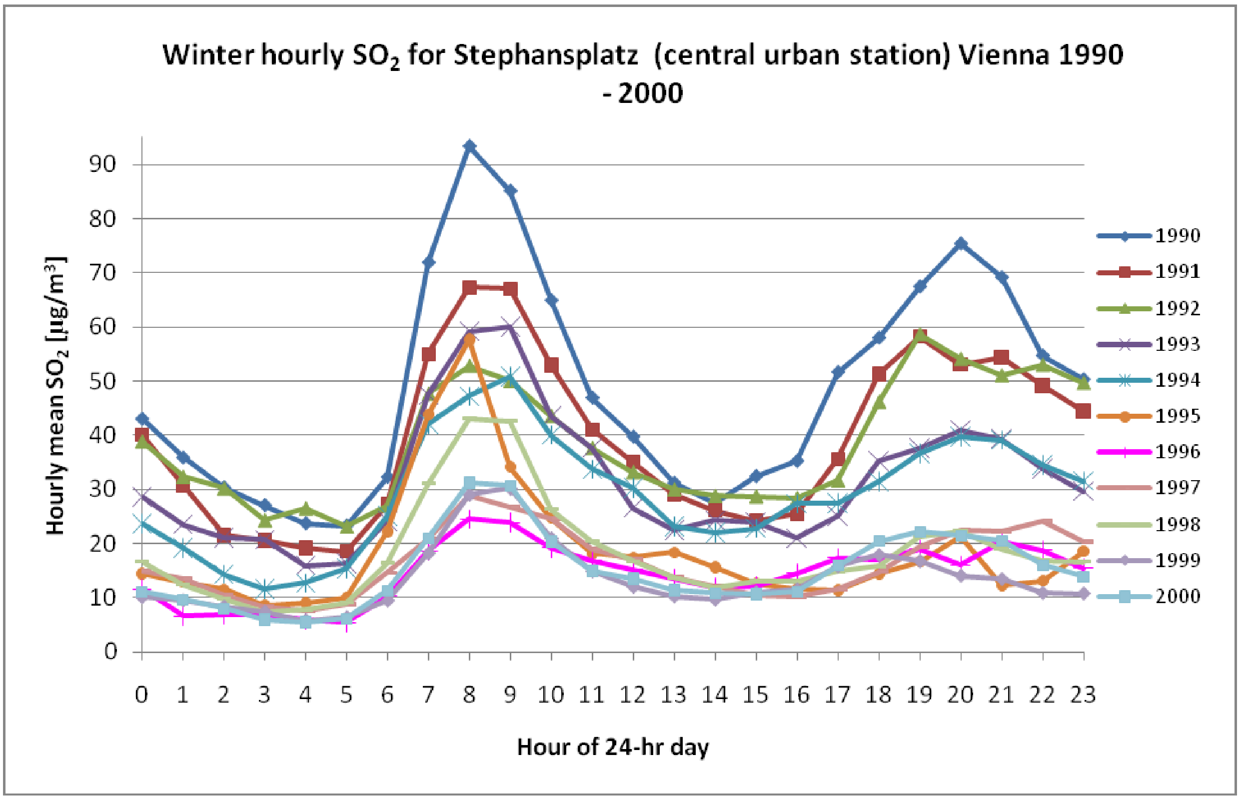

Figure 13 – Diurnal plot of winter hourly SO2 for a central urban station in Vienna 1990-2000

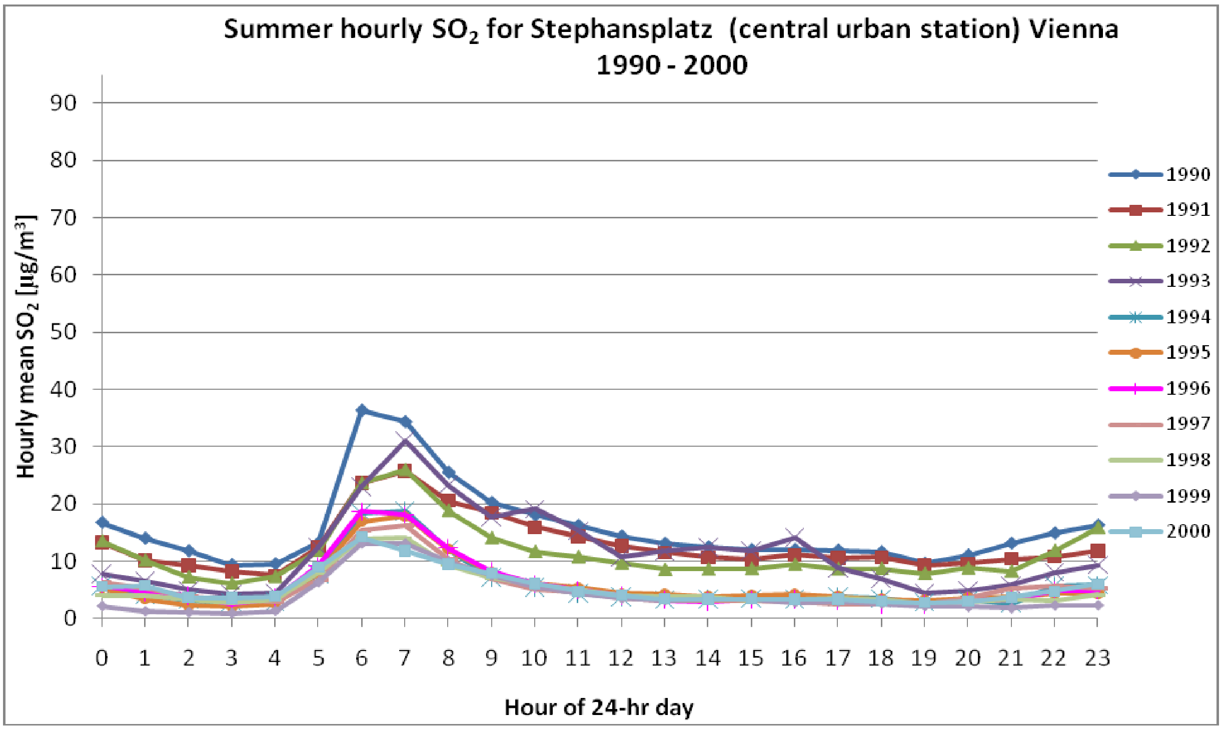

Figure 14 – Diurnal plot of summer hourly SO2 for a central urban station in Vienna 1990-2000

Figure 15 shows a 24hr-plot of hourly SO_2 data from an urban background station in London averaged for the winter months. In comparison to the pattern observed in Fig. 13 for Vienna, where 2 distinct peaks throughout the day for the winter months were observed, here in Fig.15 levels tend to rise markedly in the morning hours and then entering a plateau period with minor variations during day time and declining from 6pm in the evening in 1992 to 1998. One possible explanation for these elevated SO_2 levels during midday might be that it reflects the metropolitan life-style of the city involving constant traffic use. This constant traffic might have been picked up by the urban background measuring station as London Bloomsbury is very central in the city centre.

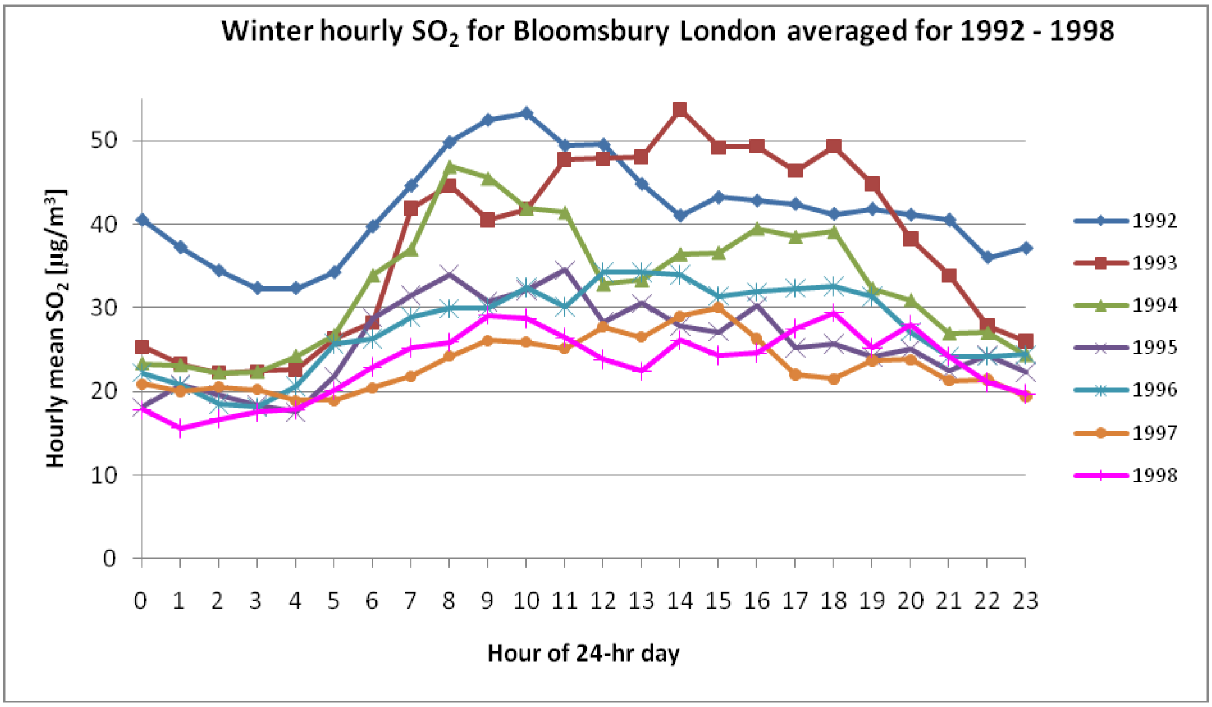

Figure 15 – Diurnal plot of winter hourly SO_2 for an urban background station in London 1992-1998

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

The local estimates are not sufficiently robust at the city level to allow a local HIA so it has been decided to use the meta results for the local economic valuation.

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.

Chapter 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.

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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 (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 1).

Table 7 – 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]	(8)
	Respiratory hospitalizations	All	1.0114 [1.0062-1.0167]	(9)
	Cardiac hospitalizations	All	1.006 [1.003-1.009]	(9)
Short-term impacts of O_3	Non-external mortality	All	1.0031 [1.0017-1.0052]	(10)
	Respiratory hospitalizations	15-64	1.001 [0.991-1.012]	(8)
	Respiratory hospitalizations	>=65	1.005 [0.998-1.012]	(8)
Long-term impacts of PM2.5	Total mortality	>30	1.06 [1.02-1.11]	(11)
	Cardiovascular mortality	>30	1.12 [1.08-1.15]	(12)

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, $\Delta x = 5\ \mu g/m^3$
- Scenario 2, $\Delta x = ([PM10]_{mean} - 20\ \mu g/m^3)$.
  $\Delta x = 0$ 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 $[O_3]_i \geq 160\ \mu g/m^3$, $O_i = ([O_3]_i - 160)$
  if $[O_3]_i < 160\ \mu g/m^3$, $O_i = 0$

- Scenario 2, if $[O_3]_i \geq 100\ \mu g/m^3$, $O_i = ([O_3]_i - 100)$
  if $[O_3]_i < 100\ \mu g/m^3$, $O_i = 0$
- Scenario 3, where the ozone yearly mean is decreased by 5 µg/m^3. $\Delta x = 5\ \mu g/m^3$

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, $\Delta x = 5\ \mu g/m^3$
- Scenario 2, $\Delta x = ([PM2.5]_{mean} - 10\ \mu g/m^3)$
  $\Delta x = 0$ if $[PM2.5]_{mean} < 10$

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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 µg/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 1 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 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.

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