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

Local city report

London

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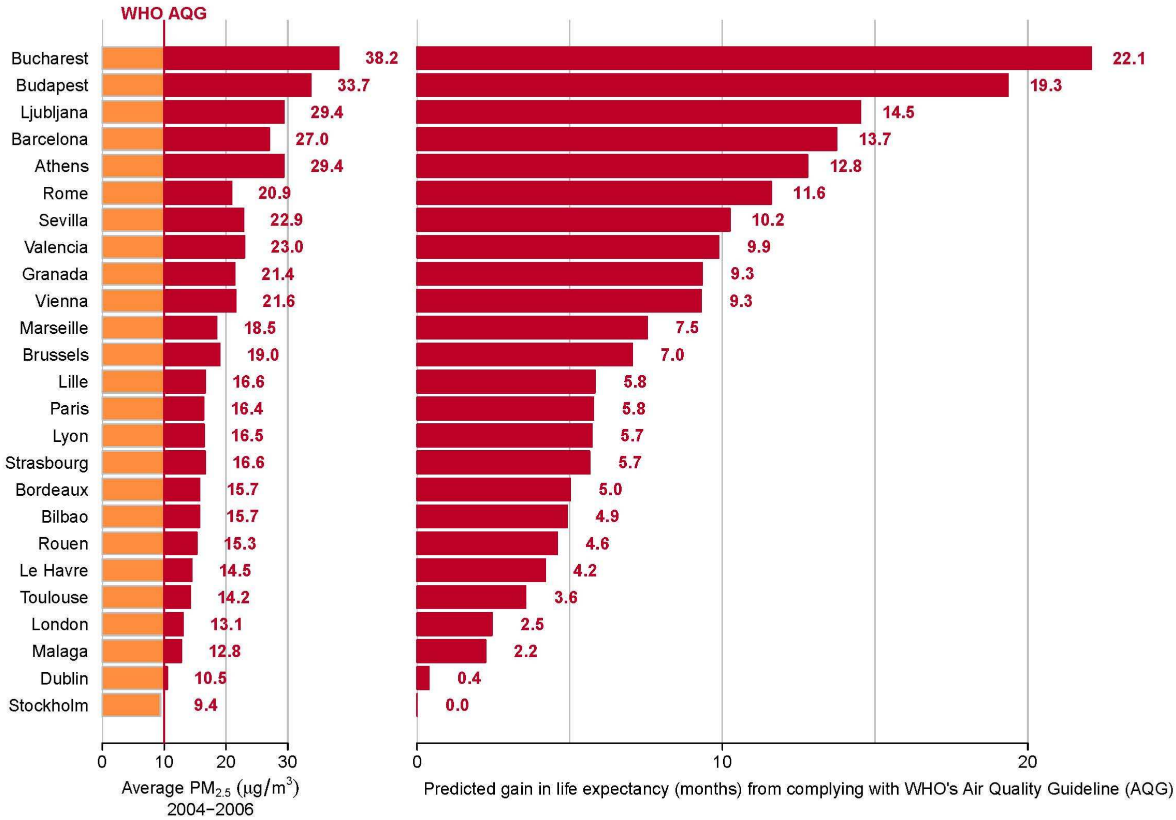
Summary

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 London. Data on mortality and hospital admissions in London 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. A decrease in long-term average PM_{10} concentrations by 5µg/m^3, and to 20µg/m^3, has the potential to reduce the annual number of deaths attributable to PM_{10} by 2/100,000 and 1/100,000 of the population over the age of 30 years under each scenario. For $PM_{2.5}$ reductions in concentrations by 5µg/m^3 and to 10µg/m^3 could reduce attributable mortality by 22/100,000 and 41/1000.

Across the 25 European cities the benefits of reducing levels of $PM_{2.5}$ fine particles (WHO's annual air-quality guideline) could add up to an additional 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. The results for $PM_{2.5}$ are summarised in the figure below:



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 $PM_{2.5}$ 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 Organisation

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.

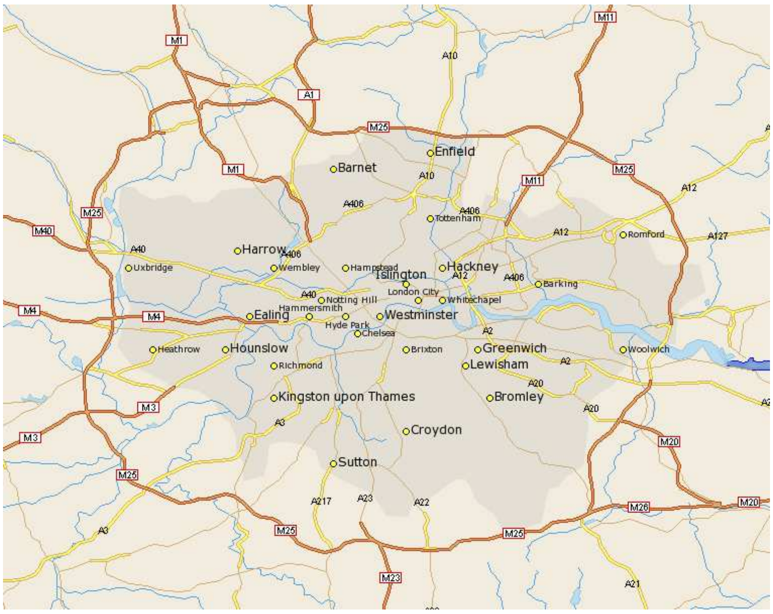
Chapter 1. Standardised HIA in 25 Aphekom cities

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. Each participating centre collated data on health and air pollution using a standardised data collection protocol. These data were analysed centrally using a standard statistical protocol to provide city specific results as well as project-wide results. The project assessed the potential benefits of reductions in ozone and PM on both short and long-term impacts on mortality and hospital admissions in populations 30 years of age and older.

1.1. Description of the study area for London

Greater London comprises, approximately, the area enclosed by the orbital M25 motorway, an area of some 22km^2 in size (Figure 1). The health data used in this study are categorised by the district/region of both residence and death and it is the outer boundaries of these adjacent districts/region that determine the actual study area. London has an extensive network of air pollution monitoring stations from which the average exposure of the population in the study area can be estimated.

Figure 1 – Map of the study area



Climatology

The average temperature in London is 10.4 ℃ (51 ℉) with the highest and lowest monthly averages in July and January/February (22 ℃ (72 ℉) and 2 ° C (36 ℉) respectively. London's climate receives an average of 594 mm (23.4 in) of rainfall per year, Average sunlight hours in London range between 1.3 hours per day in December and 6.9 hours per day in June with an average of 1460 hours of sunlight per year. (Source: http://www.climatetemp.info/united-kingdom/london.html. Accessed:4th April 2011).

Population in the study area

In July 2007 London had an official population of 7,556,900 within the boundaries of Greater London, making it the most populous municipality in the European Union. London has a diverse range of peoples, cultures and religions, and more than 300 languages are spoken within its boundaries. (Source: http://en.wikipedia.org/wiki/London#Demography. Accessed 24th March 2011)

Commuting

On an average weekday (figures are for Autumn 2006) 1.1 million people entered central London during the morning peak (7am to 10am). The number of trips in London in 2006 was estimated to be 23.8 million a day of which 10% were taken on the London Underground network, 19% by Bus, 8% by Rail, 20% by foot and 39% by car. Total road traffic by motor vehicles in London rose by 1% between 2005 and 2006, after 6 years of no growth. Car traffic entering the Central London Congestion Charging Zone in 2006 remained at a similar level to that seen in 2005 (two years after the schemes implementation). The number of overseas visitors to London increased in 2006, by 13% over the previous year, continuing the upward trend since 2001. The number of passengers using London's airports also continued to grow. (source: http://www.tfl.gov.uk/assets/downloads/corporate/London-Travel-Report-2007-final.pdf

1.2. Sources of air pollution and exposure data

Sources

Detailed monitoring and modelling of emissions of a large number of air pollutants are undertaken by the National Atmospheric Emissions Inventory Table 1 summarises emission sources for England for 2008.

Table 1 – Main sources of air pollution in England

Pollutant	Road	Commercial & Domestic	Industrial Combustion	Energy Industries	Other
SO_2	40	19.5	79.6	208	47.8
NO_X	492	128	179	231	35.3
PM_{10}	26.3	14.9	28.3	7.5	22

Kilotonnes in 2008
source: http://uk-air.defra.gov.uk/reports/cat07/1010130853_DA_AQI_2008_main_text_Issue_1.pdf

Exposure data

Defra is the UK government department responsible for policy and regulations on the environment, food and rural affairs. Through its Air Quality Archive it provides access to measured pollutant concentrations from a national network of monitoring stations. For this study, daily average concentrations for the period 2004-2006 were collected from 1 background monitoring station monitoring $PM_{2.5}$, 3 monitoring and PM_{10} (both using TEOM monitors adjusted to gravimetric equivalence) and 10 monitoring ozone. Summary statistics for daily concentrations (averaged across the 3 and 10 stations for PM_{10} and ozone respectively) are given below.

Table 2 – **Daily mean levels, standard deviation and 5th and 95th percentiles for air pollutants**

Pollutant	Daily mean (µg/m³)	Standard deviation (µg/m³)	*5th percentile* (µg/m³)	*95th percentile* (µg/m³)
Ozone (daily 8h-max)	51	24	11	88
$PM_{2.5}$ (daily average)	19	8	11	31
PM_{10} (daily average)	21	9	11	39

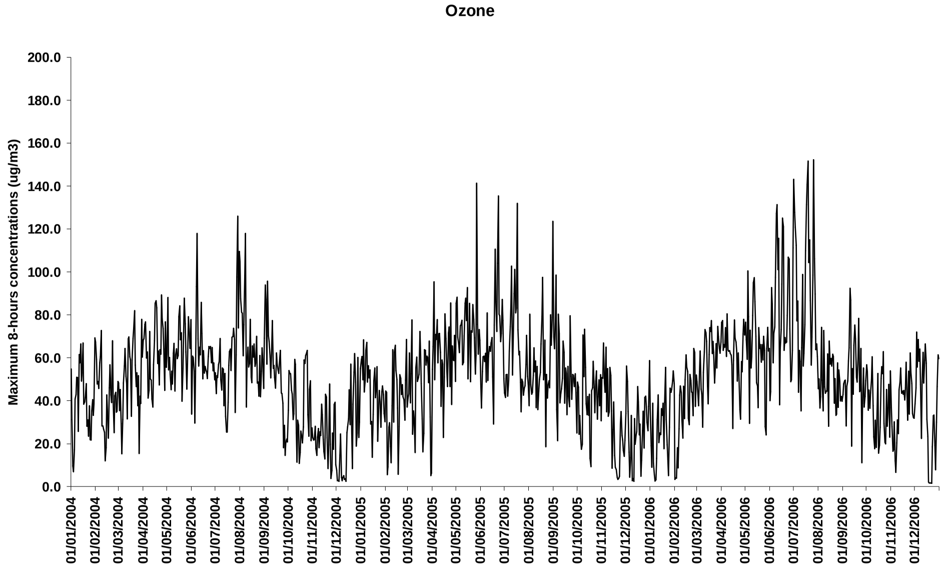


Figure 2 – Daily maximum 8-hour Ozone Concentration, London, 2004-2006

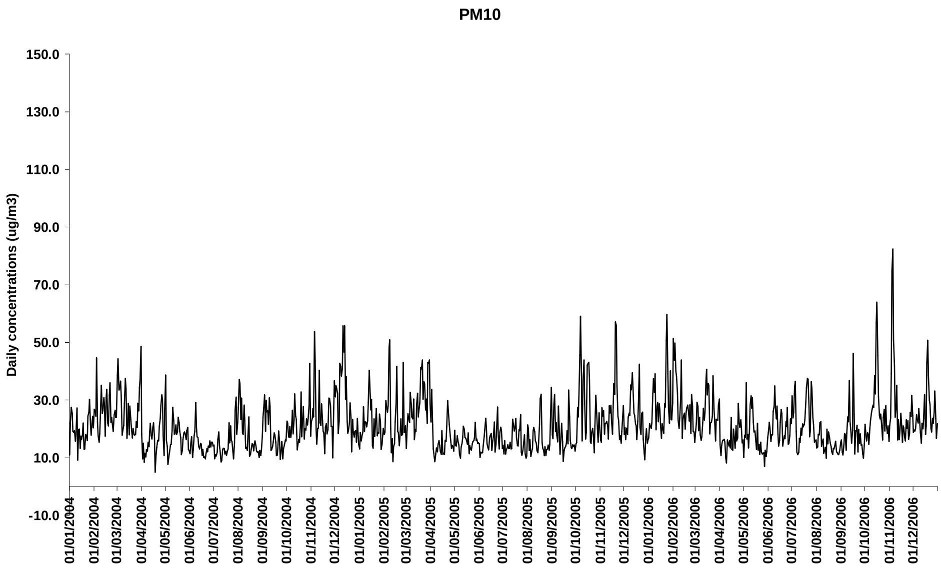


Figure 3 – Daily PM_{10} concentration, London, 2004-2006

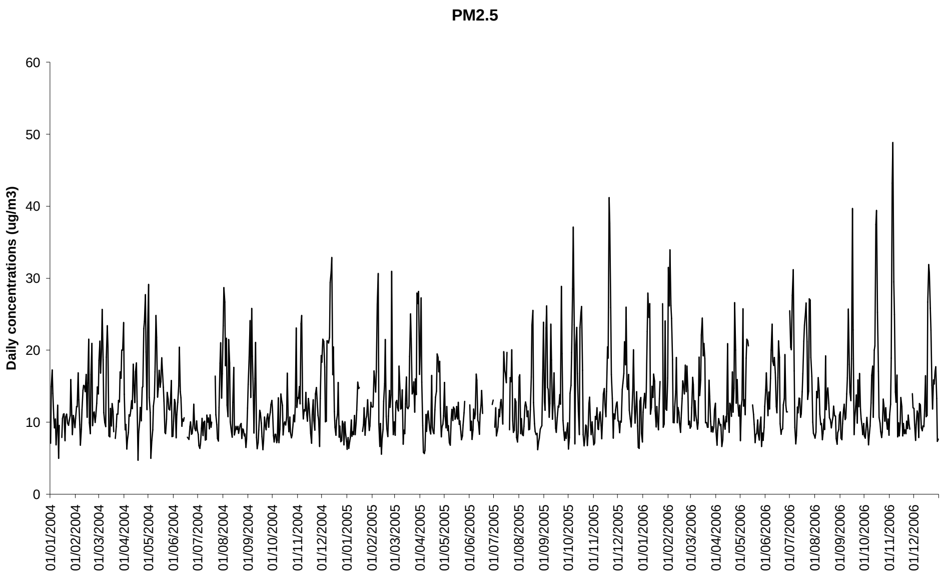


Figure 4 – Daily $PM_{2.5}$ concentration, London, 2004-2006

1.3. Health data

Mortality data were obtained from the Office for National Statistics and hospitalisation data from the Hospital Episode Statistics system.

Table 3 – 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	50364	673
Cardiac hospitalizations	390-429	I00-I52	All	40122	536
Respiratory hospitalizations	460-519	J00-J99	15-64	19240	257
Respiratory hospitalizations	460-519	J00-J99	>65	28290	378
Respiratory hospitalizations	460-519	J00-J99	All	92491	1236

*** 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. It is important to note that the HIA findings for the different air pollutants cannot 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 PM_{10}

For PM_{10}, we first considered a scenario where the annual mean of PM_{10} is decreased by 5µg/m^3, and then a scenario where the PM_{10} annual mean is decreased to 20µg/m^3, the WHO annual air quality guideline (WHO-AQG). The results are presented in Tables 4 and 5 and illustrated in Figure 5.

Table 4 – Potential benefits of reducing annual PM_{10} levels on total non-external* mortality

Scenarios	Annual number of attributable deaths avoided	Annual number of attributable deaths avoided per 100,000
Decrease by 5µg/m^3	150	2
Decrease to 20µg/m^3	39	1

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

Table 5 – Potential benefits of reducing annual PM_{10} levels on hospitalisations

	Respiratory hospitalizations		Cardiac hospitalizations	
Scenarios	**Annual number of attributable admissions avoided**	**Annual number of attributable admissions avoided per 100,000**	**Annual number of attributable admissions avoided**	**Annual number of attributable admissions avoided per 100,000**
Decrease by 5µg/m^3	523	7	120	2
Decrease to 20µg/m^3	137	2	31	0

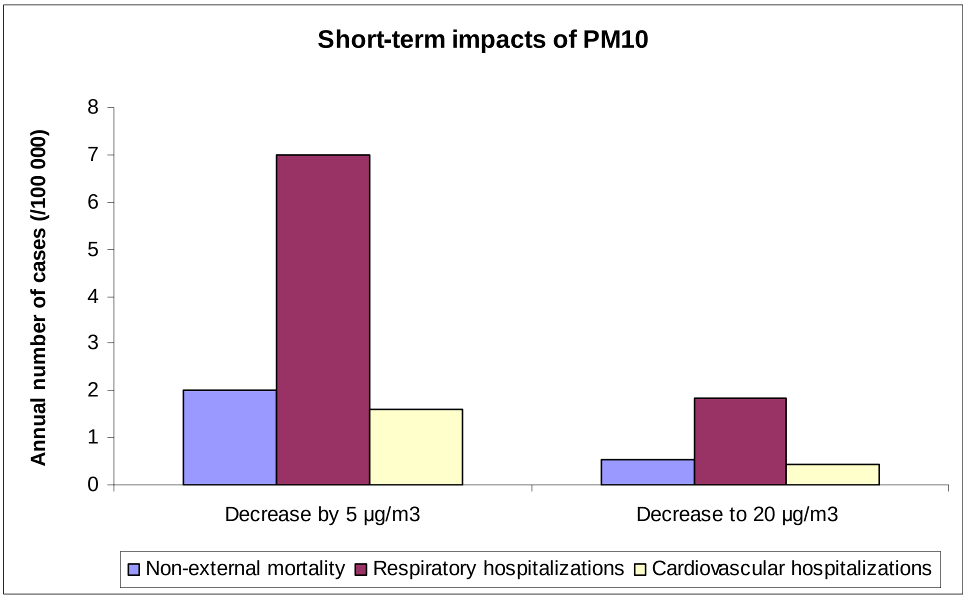


Figure 5 – Potential benefits of reducing annual PM10 levels on mortality and on hospitalisations

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. Results for each of these scenarios are presented in Tables 6 & 7 and illustrated in Figure 6

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

Scenarios*	Annual number of attributable deaths avoided	Annual number of attributable deaths avoided per 100,000
Decrease to 160µg/m^3	0	0
Decrease to 100µg/m^3	10	0
Decrease by 5 µg/m^3	78	1

8h max daily values >160 µg/m^3 to160 µg/m^3 and >100 µg/m^3 to 100 µg/m^3
* 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)		Cardiac hospitalizations (>64)	
Scenarios	**Annual number of attributable admissions avoided**	**Annual number of attributable admissions avoided per 100,000**	**Annual number of attributable admissions avoided**	**Annual number of attributable admissions avoided 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	1	0	9	1
Decrease by 5 µg/m^3	10	0	9	1

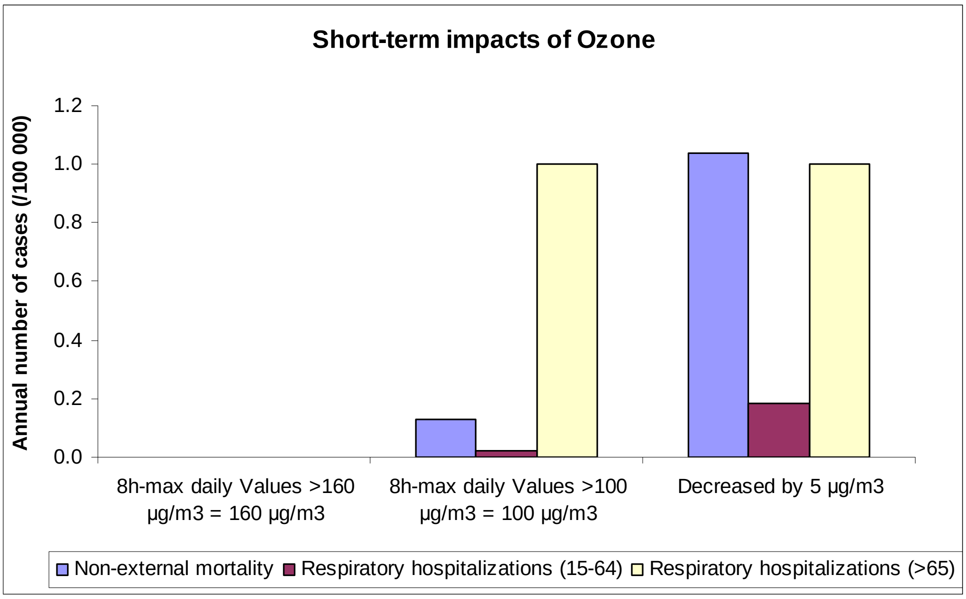


Figure 6 – **Potential benefits of reducing daily ozone levels on mortality and on hospitalisations**

1.4.3. Long-term impacts of $PM_{2.5}$

For $PM_{2.5}$, we first considered a scenario where the $PM_{2.5}$ annual mean is decreased by 5µg/m^3, and then a scenario where the $PM_{2.5}$ annual mean is decreased to 10µg/m^3 (WHO AQG). Results for each of these scenarios are presented in Tables 8 & 9 and illustrated in Figure 7.

Table 8 – Potential benefits of reducing annual $PM_{2.5}$ levels on total mortality and on life expectancy

Scenarios	Annual number of attributable deaths avoided	Annual number of attributable deaths avoided per 100,000	Gain in life expectancy
Decrease by 5µg/m^3	1420	32	0.3
Decrease to 10µg/m^3	2615	59	0.6

Table 9 – Potential benefits of reducing annual $PM_{2.5}$ levels on total cardiovascular mortality

Scenarios	Annual number of attributable deaths avoided	Annual number of attributable deaths avoided per 100,000
Decrease by 5 µg/m^3	982	22
Decrease to 10 µg/m^3	1788	41

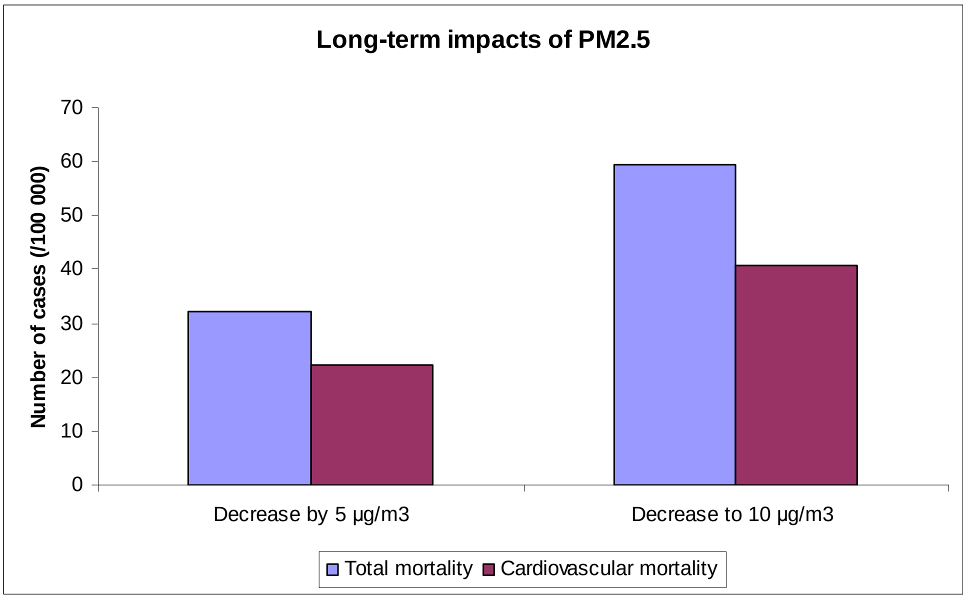


Figure 7 – Potential benefits of reducing annual $PM_{2.5}$ levels on mortality

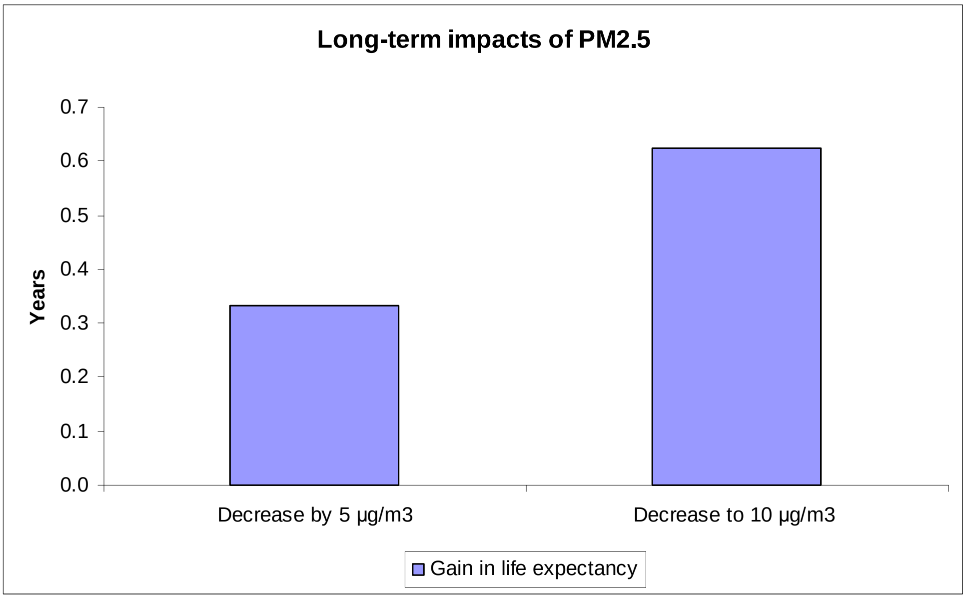


Figure 8 – Potential benefits of reducing annual $PM_{2.5}$ levels on life expectancy

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 differ depending on the short- or long-term nature of the exposure to air pollution (see Appendix 2). For attributable deaths avoided due to short-term exposure to pollution the monetary cost was estimated at €86,600. Hence for a reduction of 5µg/m^3 in average PM_{10} levels in London the estimates saving is €13m. Savings arising from long term exposure were higher at € 1,655,000 per death.

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

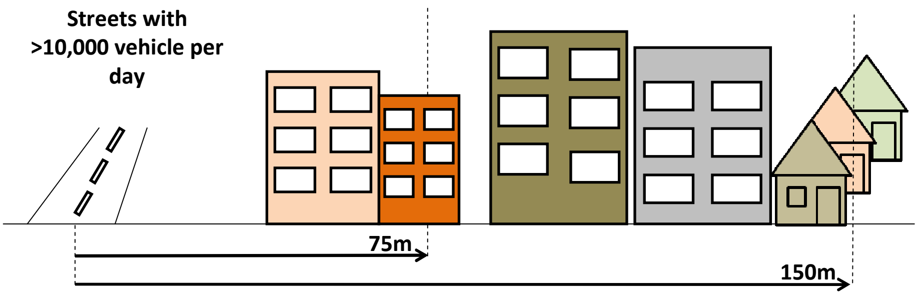
In this report the APHEKOM team have derived estimates of the health impact of both short- and long-term exposure to particles and ozone. These impacts have been estimated as the numbers of deaths and admissions attributable to air pollution avoided under different reduction scenarios. Further, these benefits have been quantified in monetary terms. Whilst there remains considerable uncertainty in the health h impact assessment and in the quantification these results illustrate the magnitude of the potential benefits associated with reductions in air pollution in London and more widely across Europe. It should be noted that the benefits reported are not considered to be independent of each other and are therefore not additive across pollutants.

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.



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 9 – Estimated percentage of people living 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.

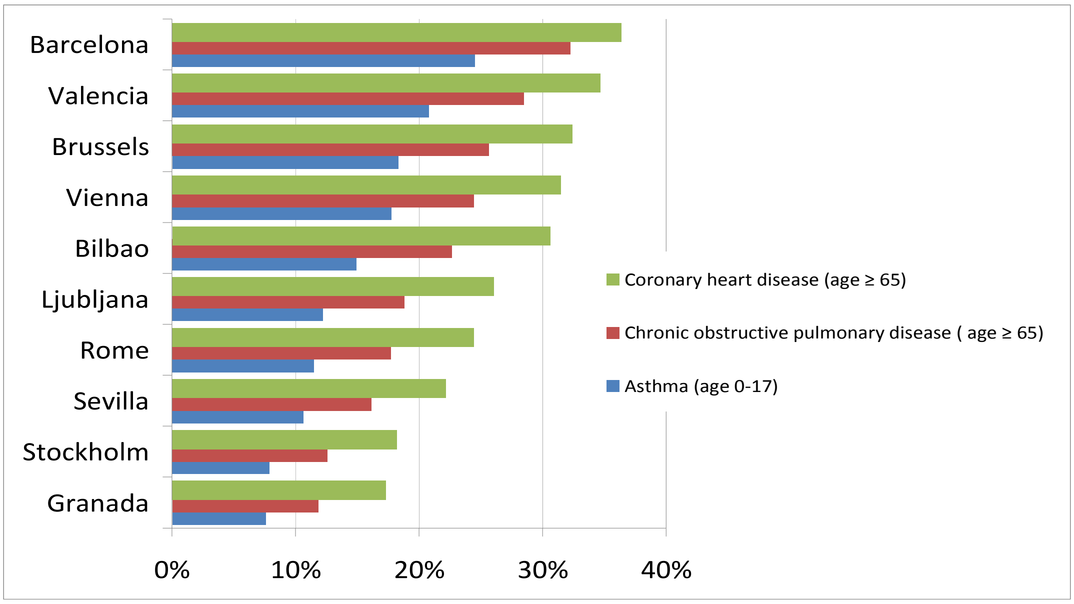


Figure 10 – Percentage of population with chronic diseases whose disease is attributable to living near busy streets and roads in 10 Aphekom cities

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.

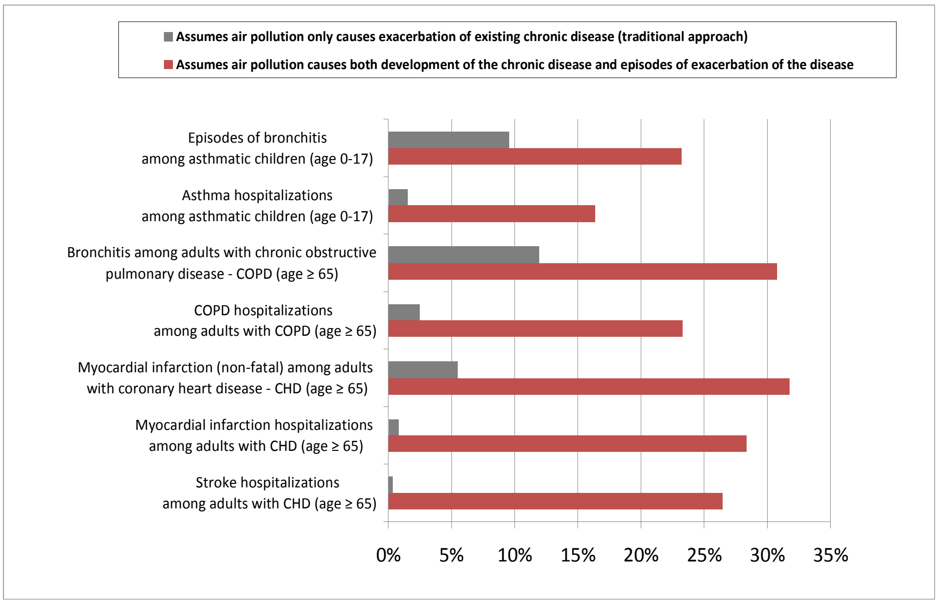


Figure 11 – Comparison of impact of air pollution on chronic diseases calculated using two different HIA approaches in Aphekom

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).

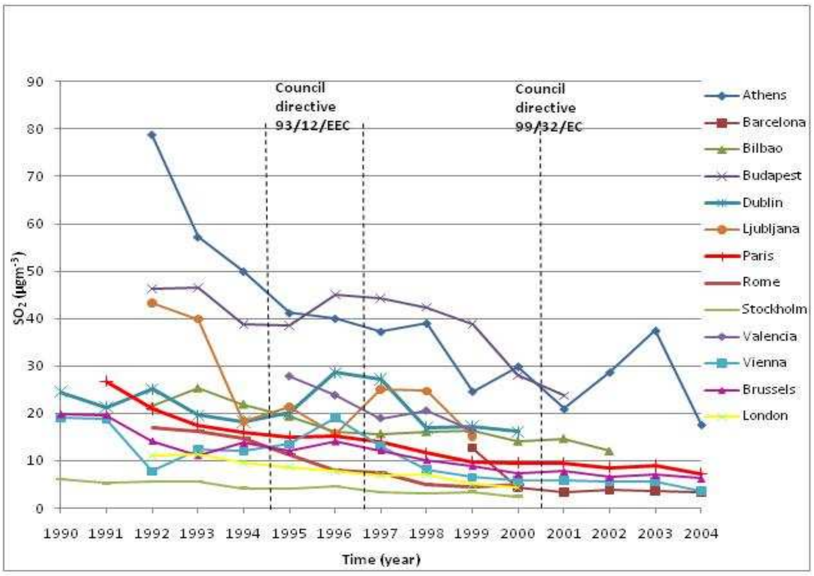


Figure 12 – Yearly urban background SO_2 averages for 13 Aphekom cities from 1990 to 2004

Figures 13 and Figure 14 show preliminary work done using hourly SO_2 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 SO_2 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 SO_2 levels for the afore mentioned time periods. This might indicate the proportion of SO_2 that resulted from emissions due to heating during the winter months especially as high SO_2 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 SO_2 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 SO_2 levels do not necessarily have to be caused by traffic! It is not clear, if these high SO_2 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.

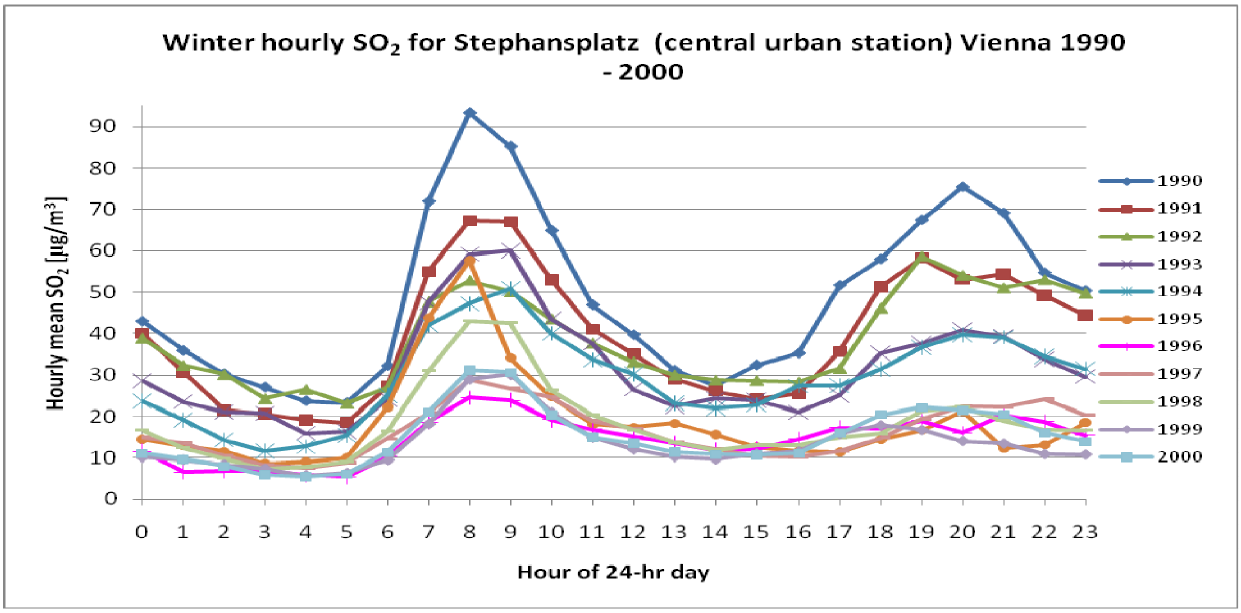


Figure 13 – Diurnal plot of winter hourly SO_2 for a central urban station in Vienna 1990-2000

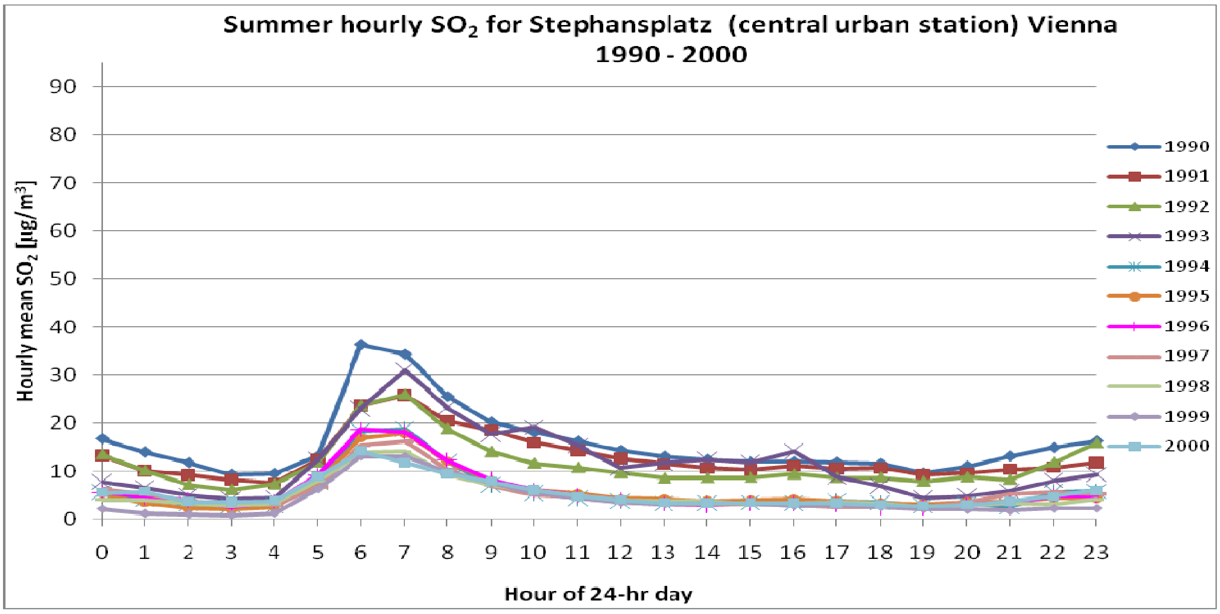


Figure 14 – Diurnal plot of summer hourly SO_2 for a central urban station in Vienna 1990-2000

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.

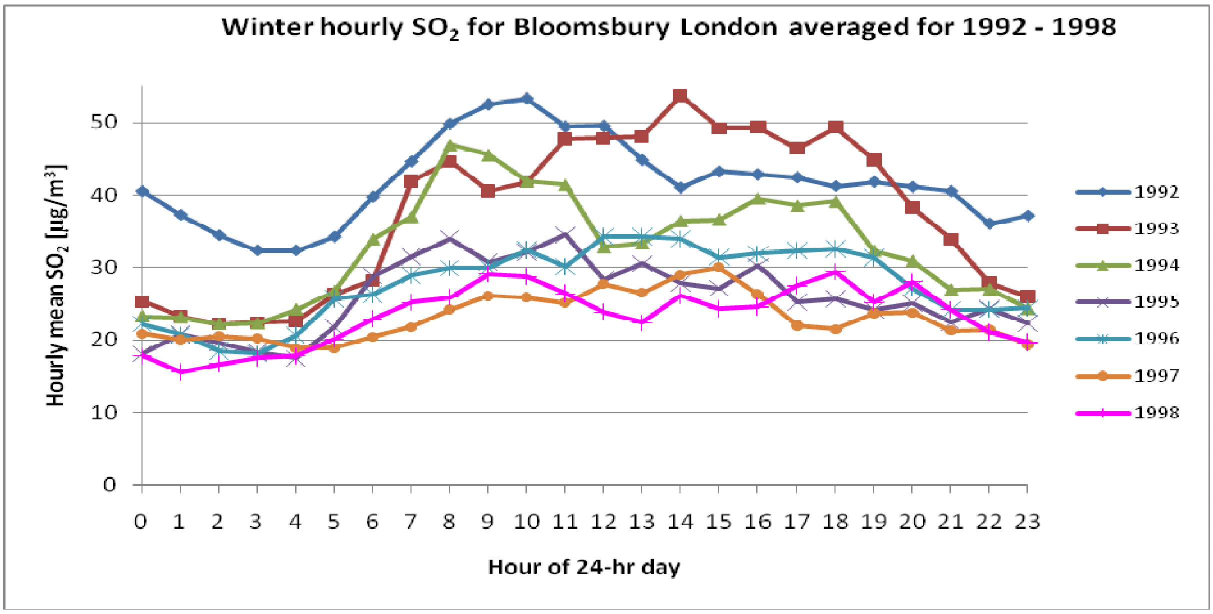


Figure 15 – Diurnal plot of winter hourly SO_2 for an urban background station in London 1992-1998

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 was decided that, to take a conservative standpoint, mortality effects would be considered as short-term effects. The value of a life year (VOLY) was estimated to be €86,600. Our analysis in 20 cities showed not only a marked, sustained reduction in ambient SO_2 levels but also the resulting prevention of some 2,200 premature deaths valued at €192 million. The economic evaluation thus constitutes a lower bound of the mortality benefits of the legislation.

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 stakeholders 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.

Chapter 5. Overview 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. Further, these benefits have been quantified in monetary terms. Whilst there remains uncertainty in the health impact assessment and in their monetary quantification these results illustrate the magnitude of the potential benefits associated with reductions in air pollution in London and more widely across Europe. It should be noted that the benefits reported are not considered to be independent of each other and are therefore not additive across pollutants.

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 10 – 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	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).

$\Delta x = 0$ 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 $[O_3]_i \geq 160$ µg/m^3, $O_i = ([O_3]_i - 160)$
  if $[O_3]_i < 160$ µg/m^3, $O_i = 0$

- Scenario 2, if $[O_3]_i \geq 100$ µg/m^3, $O_i = ([O_3]_i - 100)$
  if $[O_3]_i < 100$ µg/m^3, $O_i = 0$
- Scenario 3, where the ozone yearly mean is decreased by 5 µg/m^3. $\Delta x = 5$ 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, $\Delta x = 5$ µg/m^3
- Scenario 2, $\Delta x = ([PM2.5]_{mean} - 10$ µg/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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