Aphekom

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

Local city report

Athens

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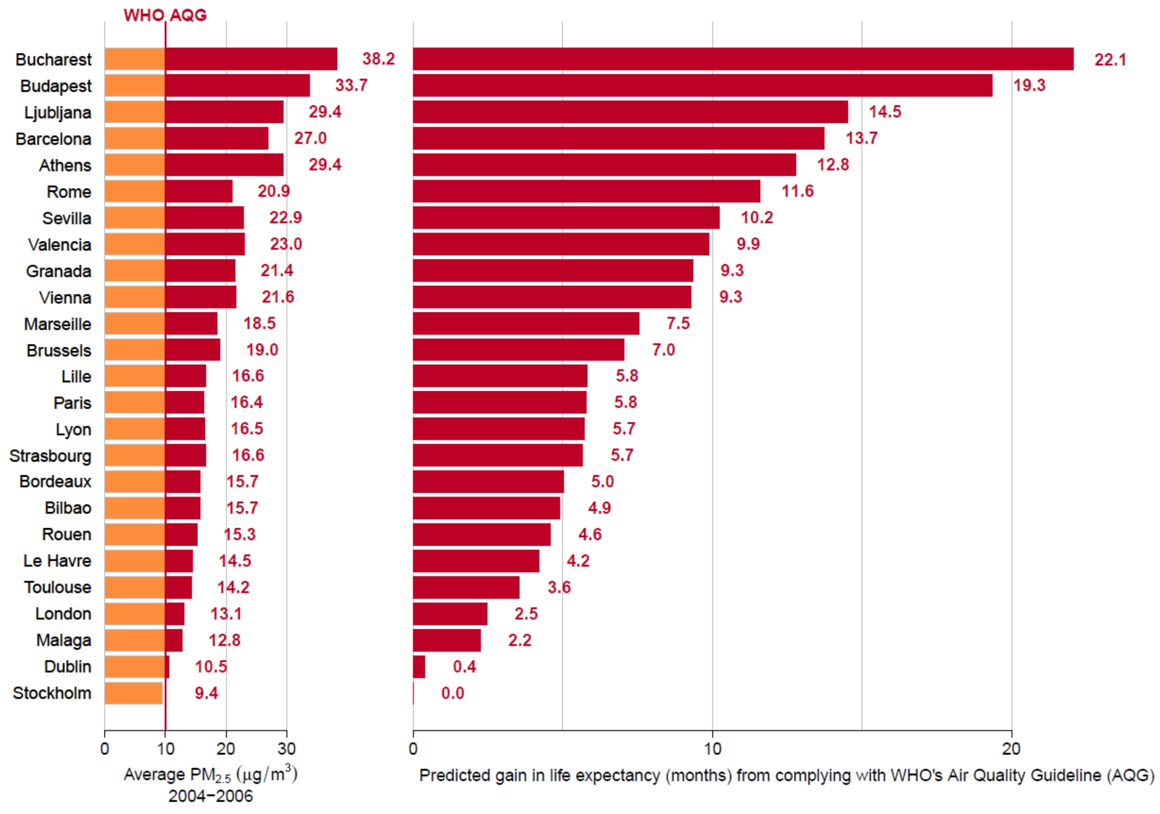
Summary

Athens was one of the 25 cities across Europe participating in the Aphekom project, a multicenter study funded by the European Commission (Grant Agreement: 2007105). Among the aims of the Aphekom project was to estimate, using standardised methodology, the benefit to human health by reductions in the air pollution levels under different scenarios. Mortality and air pollution data (PM_{10}, $PM_{2.5}$ and ozone) from 2004 to 2006 were used. Decreasing PM_{10} daily average concentrations by 5μg/m^3 and to 20μg/m^3 could save 85 and 371 premature annual deaths, respectively. A decrease in long-term average $PM_{2.5}$ concentrations by 5μg/m^3, and to 10μg/m^3 could reduce attributable cardiovascular mortality by 33 and 118 annual cases per 100,000. A 5μg/m^3 reduction in ozone daily mean levels is related to 44 avoidable annual deaths.

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/m^3 (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

O_3 : ozone

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

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

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

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 previous Apheis health impact assessments we estimated that if the long-term PM_{10} concentrations were reduced to an annual mean value of 40µg/m^3, 3068 deaths could have been avoided in the year 2001. As far as short-term effects of O_3 in summer are concerned, all other things being equal, each reduction by 10µg/m^3 of the daily maximum 8-hour moving average concentrations would delay 42 deaths per year in the general population in the study area, 31 from cardiovascular diseases, and 11 from respiratory causes.

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 PM_{10} on mortality and morbidity, as well as the long-term impacts of $PM_{2.5}$ on mortality and life expectancy in populations 30 years of age and older.

1.1. Description of the study area for Athens

The Greater Athens area consists of 57 municipalities including the cities of Athens and Piraeus. These constitute a continuous urban area with more than three million inhabitants corresponding to about 1/3 of the population of Greece (Hellenic Statistical Authority, Census 2001). It is surrounded by mountains in the west, north and the east and by the sea in the south and covers an area of about 400km^2. The major axis of the area runs from the north-east to the south-west for about 30 kilometres. Most industries lie close to the sea and the harbor of Piraeus in the south-western part of the city. Because of the topography, the climate and the size of the population, air pollutants easily reach high concentrations in the Athens Basin. The main problems are the high ozone and particles concentrations.

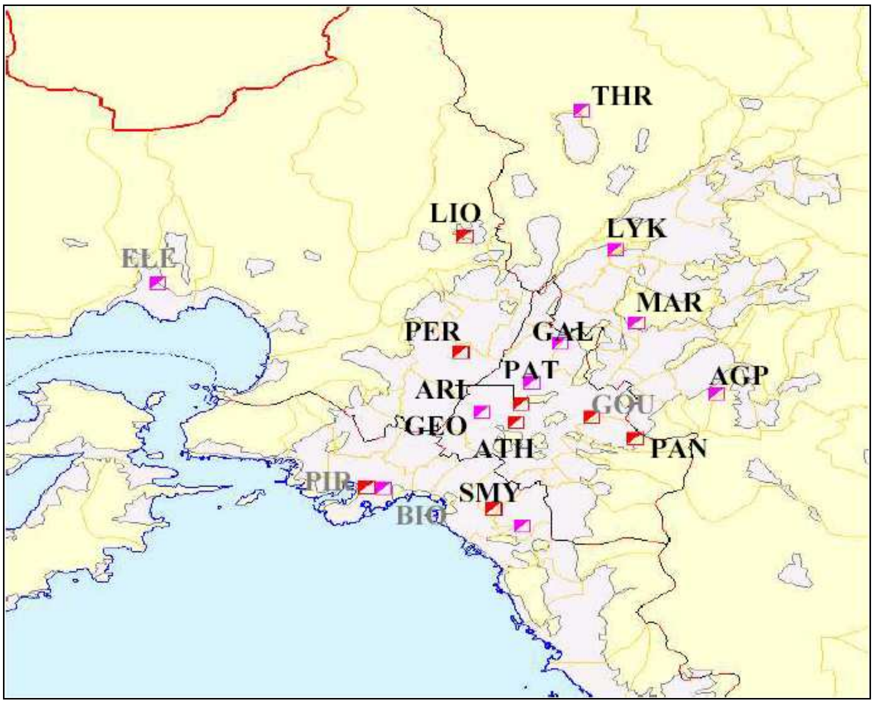


Figure 1 – Map of the study area

Climatology

The climate of the study area is Mediterranean with wet mild winters and hot dry summers. The mean daily temperature in the last decade ranged from 9.9°C in January to 29.3°C in July. Insolation is strong with average daily values on the order of $22MJm^{-2}$ in the summer and $8MJm^{-2}$ in the winter. The prevailing wind direction is north-north-east at the end of summer, in autumn and in the winter and south-south-west in spring and the beginning of the summer.

Population in the study area

The population of the Greater Athens area is about 3.4 million, 1/3 of the population of Greece. 16% of the population is above 65 years of age while 7% above 75.

Commuting

The Greater Athens area is a basin surrounded by mountains and the sea and a large proportion of the population commutes daily over large distances. The whole basin is a unified urban system.

1.2. Sources of air pollution and exposure data

Sources

The main sources of air pollution are traffic, heating (in the winter) and industrial activity. The Ministry of Environment, Energy and Climate Change, Division of Air Pollution and Noise Control (PERPA) indicates that about 70% of PM_{10} comes from vehicles (a large proportion from diesel-powered) and 30% from heating/industry.

Exposure data

The fixed site air pollution monitoring network in Athens, operated by the Ministry of Environment, Energy and Climate Change, is the source of the air pollution data. The location of the monitors is shown in Figure 1. Population exposure to air pollution for the period 2004 -2006 was estimated using the average daily values from selected urban & suburban background monitors according to pre-specified criteria. Four PM_{10} and eight ozone monitoring station were used. PM_{10} was measured using β-attenuation while ozone using UV absorption. $PM_{2.5}$ was calculated from PM_{10} using a 0.7 conversion factor. Summary statistics for daily concentrations (averaged across the 4 and 8 stations for PM_{10} and ozone respectively) are shown in table 1. In Figures 2, 3 and 4 the daily concentrations of ozone, PM_{10} and $PM_{2.5}$ over the study period are presented.

Table 1 – 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 8-h max)	83	29	38	128
PM_{10} (daily average)	42	22	21	69
$PM_{2.5}$ (daily average)	29	16	14	48

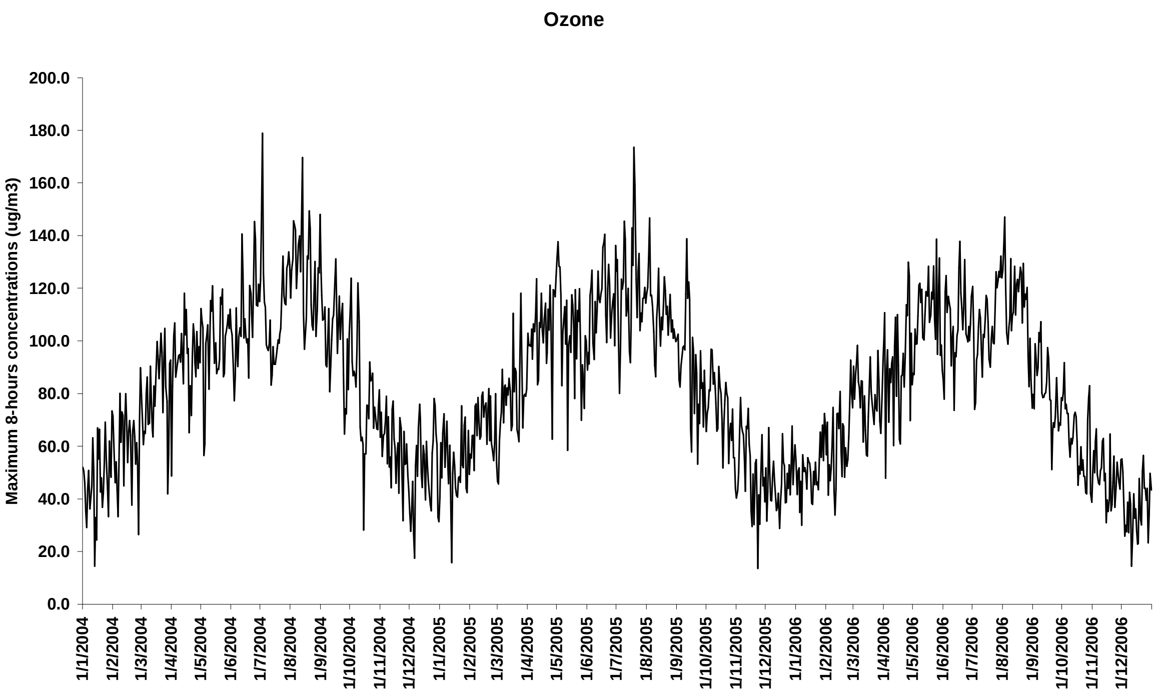


Figure 2 – Ozone (daily 8h max) concentration in Athens, 2004-2006

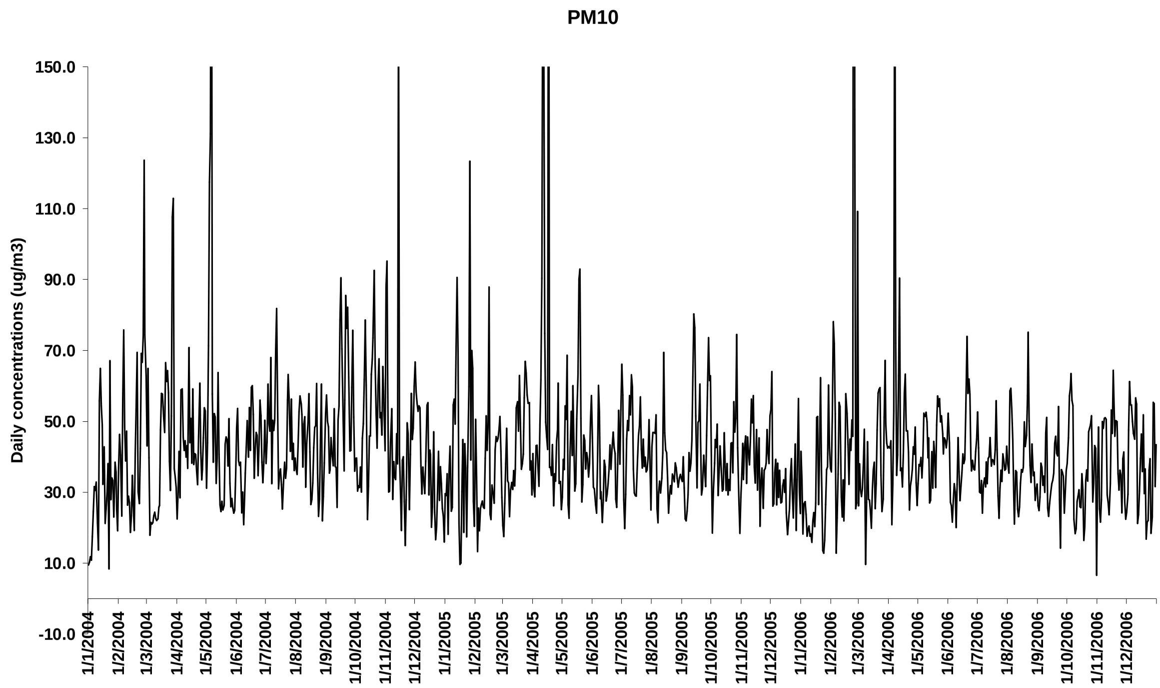


Figure 3 – PM_{10} (daily average) concentration in Athens, 2004-2006

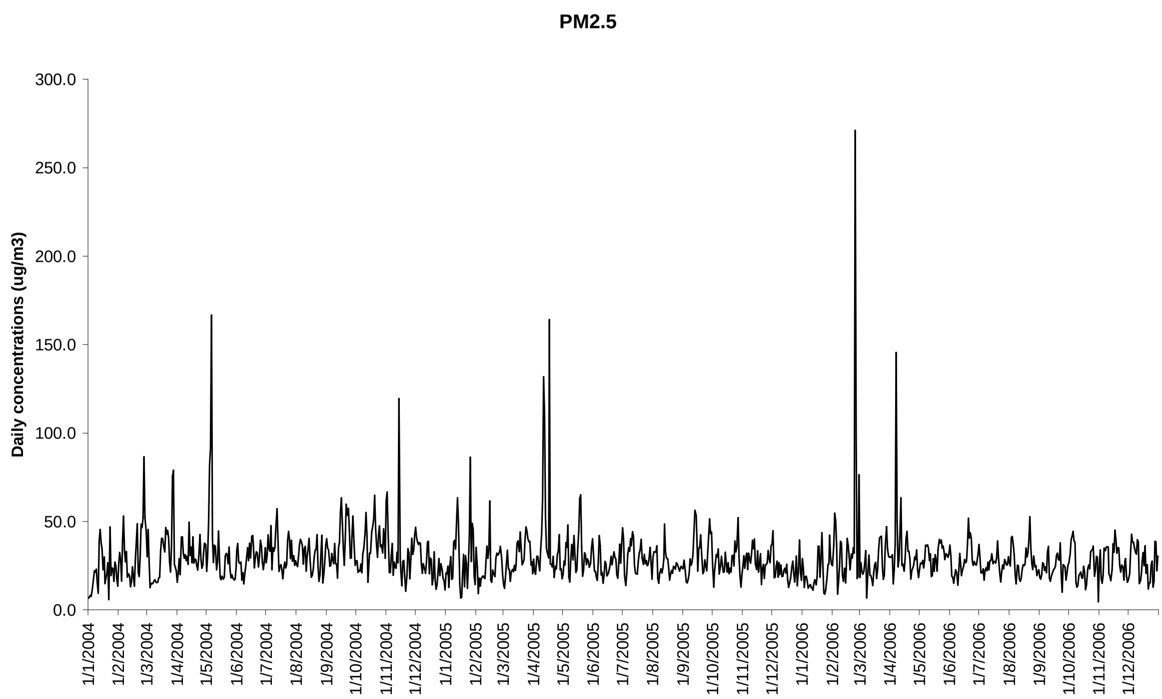


Figure 4 – $PM_{2.5}$ (daily average) concentration in Athens, 2004-2006

1.3. Health data

All cause and cause-specific mortality data were provided by the Hellenic Statistical Authority, following a specific request. Hospital admission data and other morbidity indicators are not collected in Greece on a regular basis and were therefore not included in the present report. Descriptive statistics are shown in Table 2.

Table 2 – Annual mean number and annual rate per 100 000 deaths (2004-2006)

Health outcome	ICD9	ICD10	Age	Annual mean number	Annual rate per 100 000
Non-external mortality*	< 800	A00-R99	All	28460	834
Total mortality	000- 999	A00-R99	> 30	29041	1269
Cardiovascular mortality	390-429	I00-I52	> 30	13681	598

*** 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 PM10, 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 Table 3 and illustrated in Figure 5.

Table 3 – 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 5µg/m^3	85	2
Decrease to 20µg/m^3	371	11

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

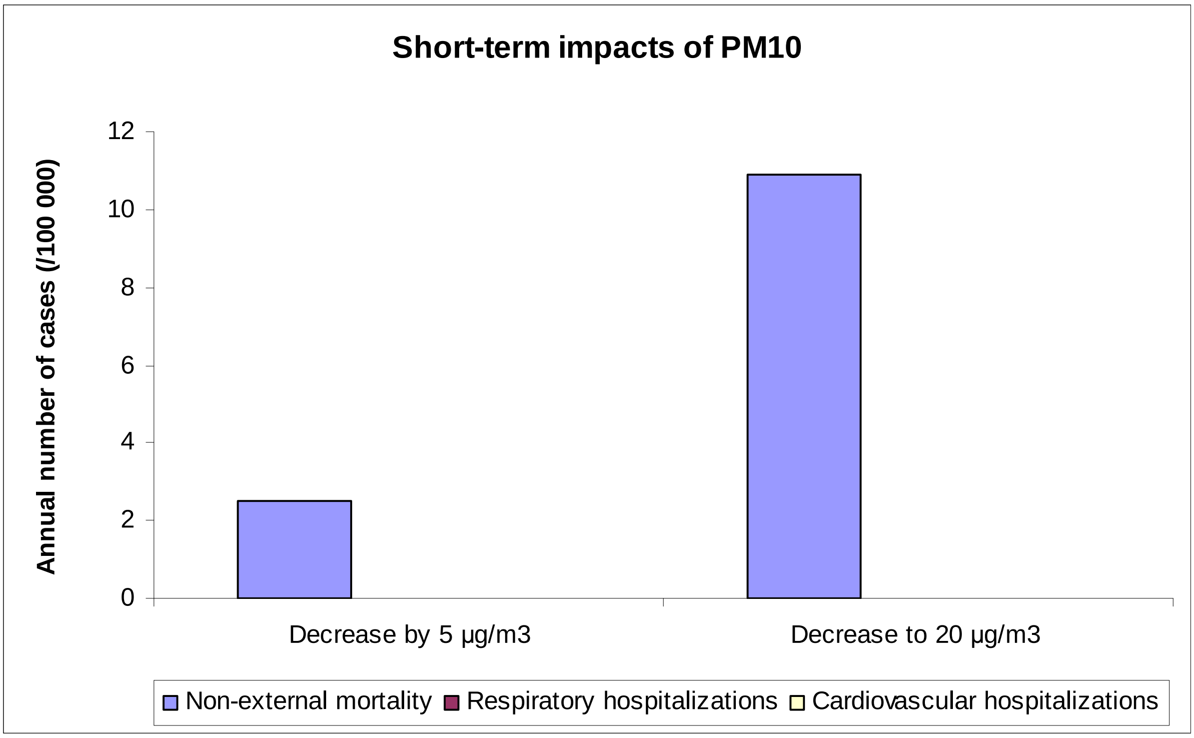


Figure 5 ─ Potential benefits of reducing annual PM_{10} levels on mortality

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 160µg/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 100µg/m^3.

We first considered a scenario where all daily values above 160µg/m^3 were reduced to WHO-IT (160 µg/m^3), then a scenario where all daily values above 100µg/m^3 were reduced to WHO-AQG (100 µg/m^3), and lastly a scenario where the daily mean is decreased by 5µg/m^3. Results for each of these scenarios are presented in Table 4 and illustrated in Figure 6.

Table 4 ─ 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	47	1
Decrease by 5 µg/m^3	44	1

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

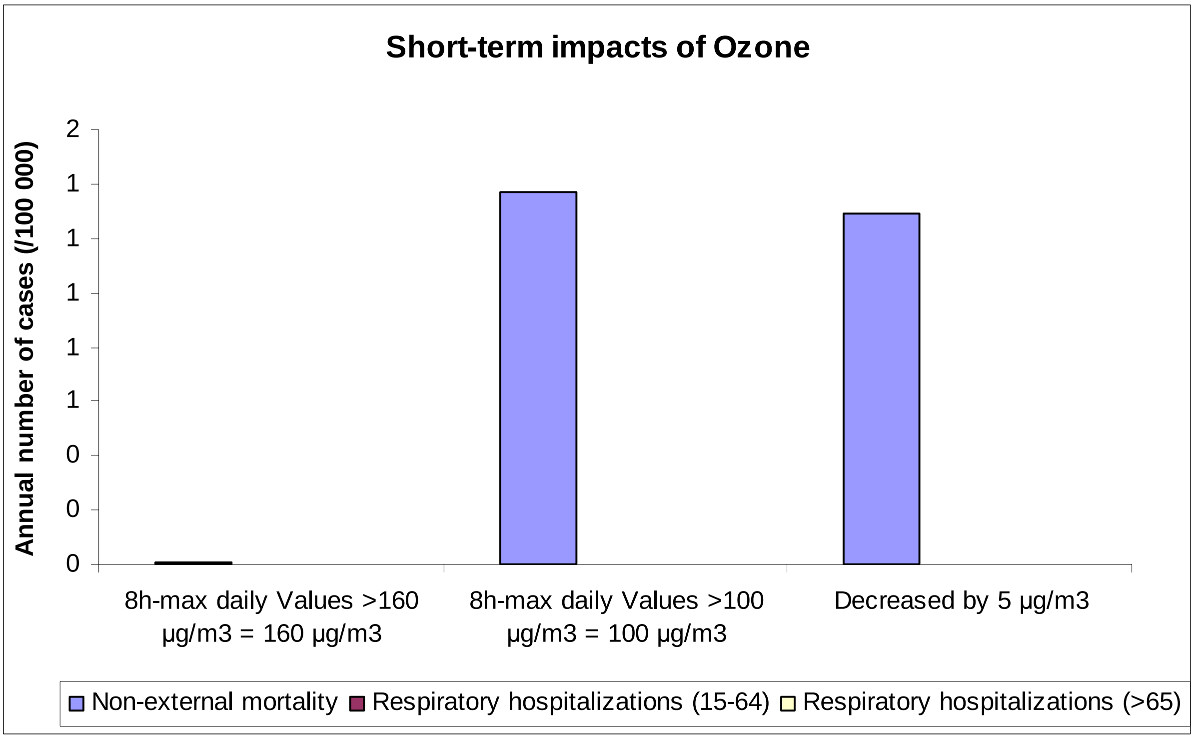


Figure 6 – Potential benefits of reducing daily ozone levels on mortality

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 5 & 6 and illustrated in Figures 7 & 8.

Table 5 – Potential benefits of reducing annual $PM_{2.5}$ levels on total non-external* mortality and on life expectancy at age 30

Scenarios	Total annual number of deaths postponed	Annual number of deaths postponed per 100 000	Gain in life expectancy
Decrease by 5µg/m^3	834	36	0.3
Decrease to 10µg/m^3	3099	135	1.1

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

Table 6 – Potential benefits of reducing annual $PM_{2.5}$ levels on total cardiovascular mortality

Scenarios	Total annual number of deaths posponed	Annual number of deaths postponed per 100 000
Decrease by 5µg/m^3	754	33
Decrease to 10µg/m^3	2696	118

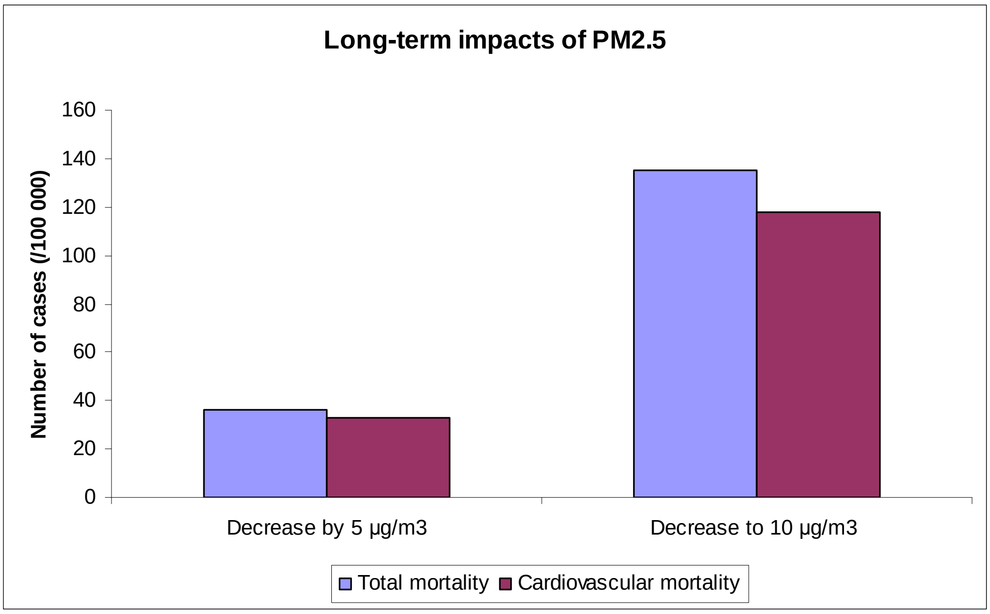


Figure 7 – Potential benefits of reducing annual $PM_{2.5}$ levels on mortality

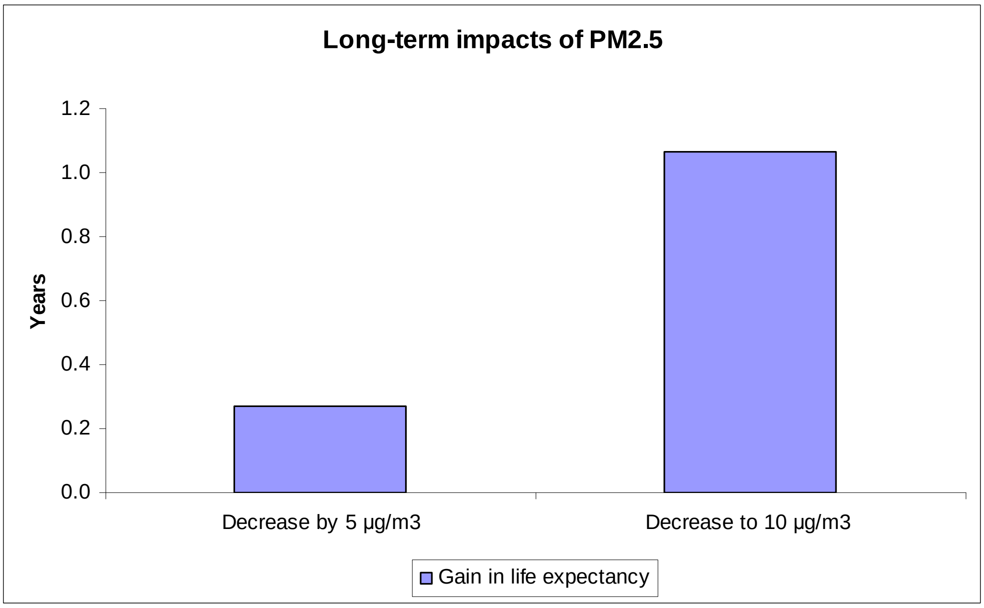


Figure 8 – Potential benefits of reducing annual $PM_{2.5}$ levels on life expectancy at age 30

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).
The estimated monetary cost due to short term exposure to air pollution was estimated at €86,600. Thus for a reduction in mean daily PM_{10} levels by 5µg/m^3 the avoided deaths are associated with an avoided cost of €7.3 million. For long-term impacts, the monetary value of €1,655,000 should be multiplied by the total annual number of deaths postponed.

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.

1.4.5. Interpretation of findings

The benefits from reductions of the air pollution levels in Athens are significant both in terms of avoided deaths and in terms of monetary savings. A 5µg/m^3 reduction in the daily average PM_{10} levels, which is a more feasible scenario, could lead to 85 avoided annual deaths, associated with €7.3 million savings. A reduction of PM_{10} levels at 20µg/m^3 could prevent 371 premature deaths related to the short term effects of the pollutant. For ozone, reduction to 100µg/m^3 has similar benefits with a reduction by 5µg/m^3 (due to concentration levels) and could prevent 47 premature annual deaths. Quite more impressive are the benefits in human health due to reduction in long term exposure to $PM_{2.5}$ and associated monetary savings (834 deaths avoided for a 5µg/m^3 reduction, €1,655,000 saved per avoided death).

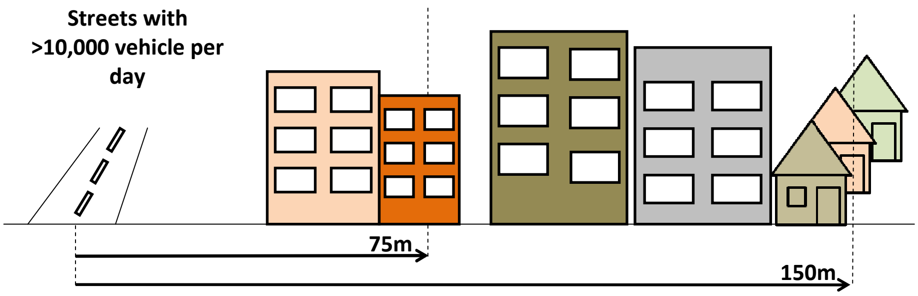
Benefits for the different air pollutants cannot be added together because all represent to some extent the same urban air pollution mixture and their estimated health impacts overlap. Although uncertainties are still present in these estimations, the findings show the magnitude of the benefits by improving air quality.

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 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.

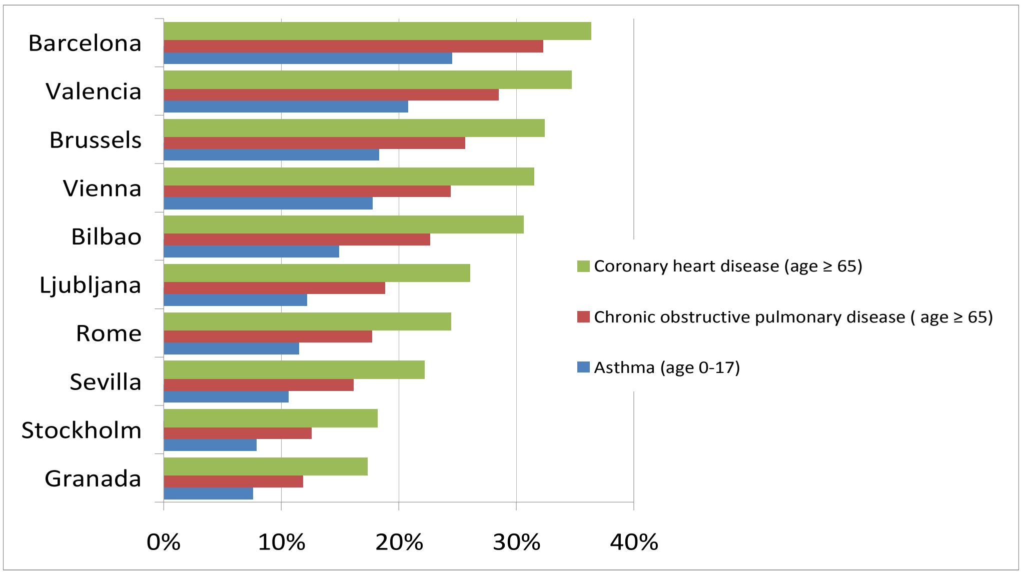


Figure 10 – Percentage of population with chronic diseases whose disease is attributable to living near busy streets and roads in 10 Aphekom cities

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.

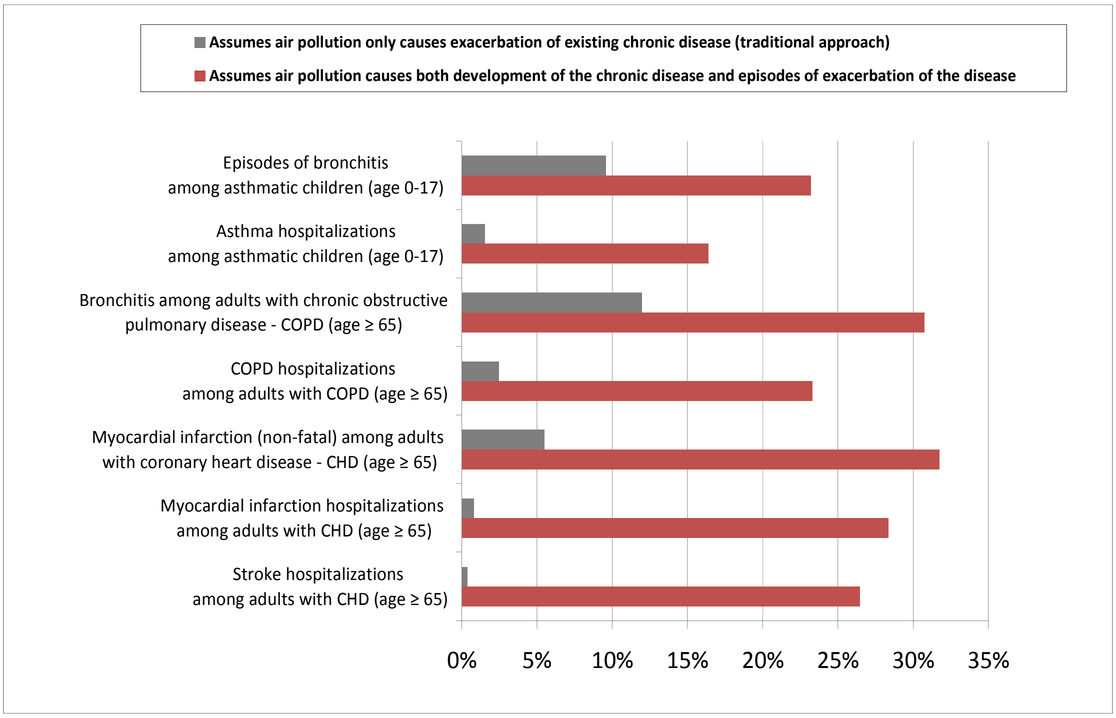


Figure 11 – Comparison of impact of air pollution on chronic diseases calculated using two different HIA approaches in Aphekom

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).

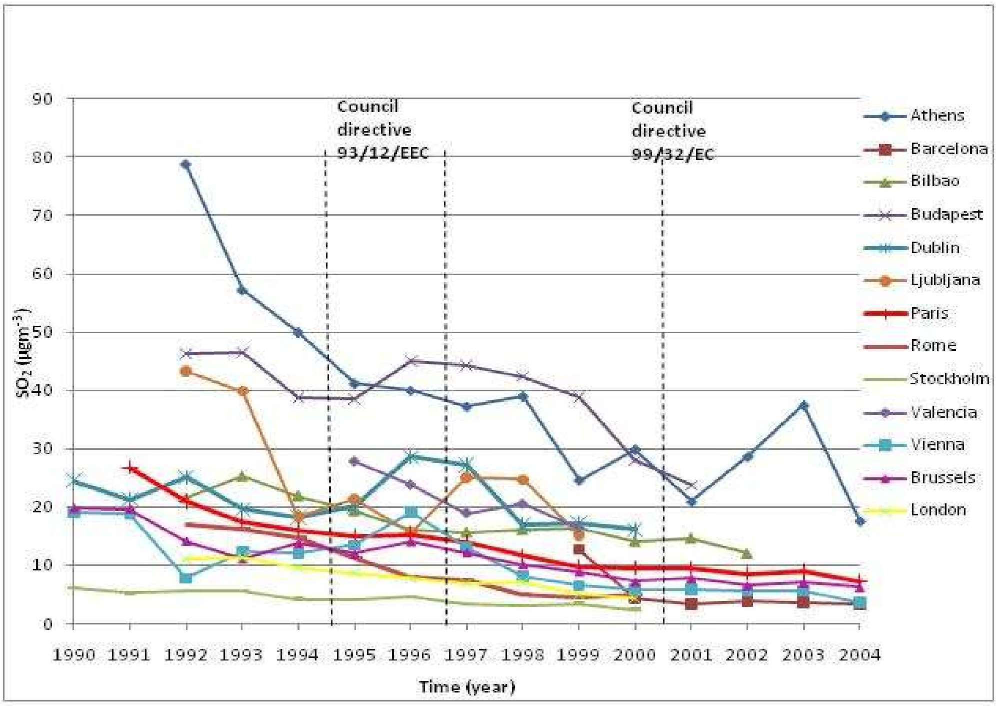


Figure 12 – Yearly urban background SO_2 averages for 13 Aphekom cities from 1990 to 2004

A decreasing trend in SO_2 levels is evident in all participating cities as well as in Athens.

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.

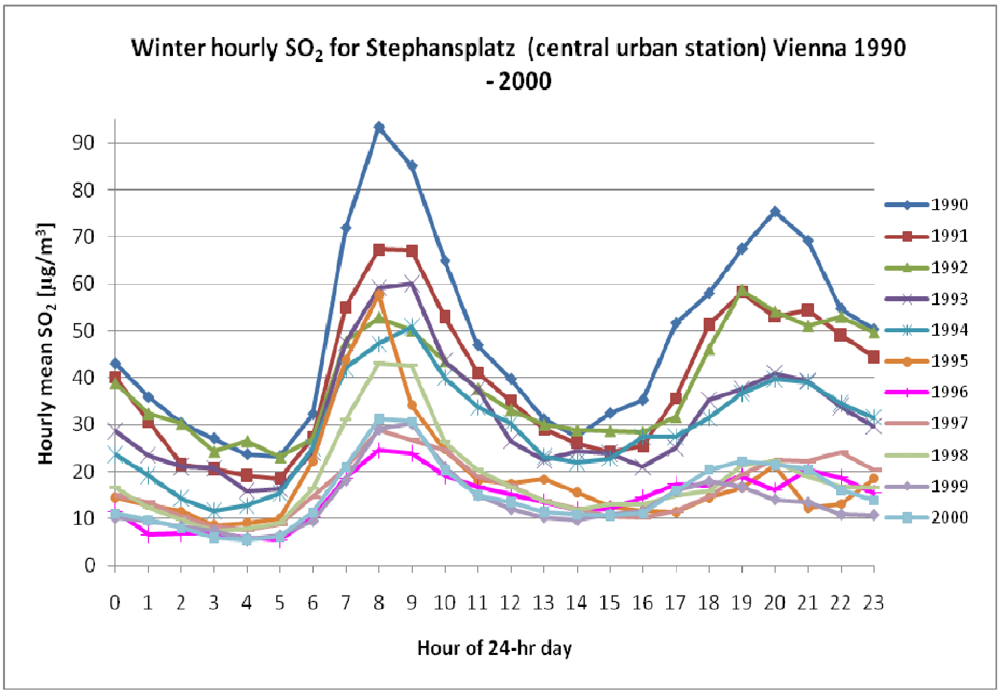


Figure 13 – Diurnal plot of winter hourly SO_2 for a central urban station in Vienna 1990-2000

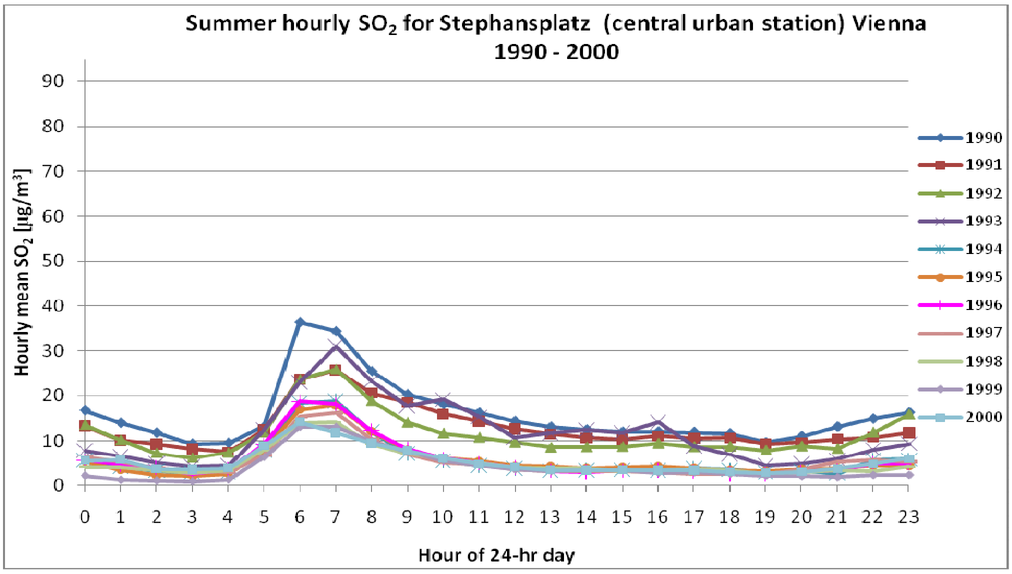


Figure 14 – Diurnal plot of summer hourly SO_2 for a central urban station in Vienna 1990-2000

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.

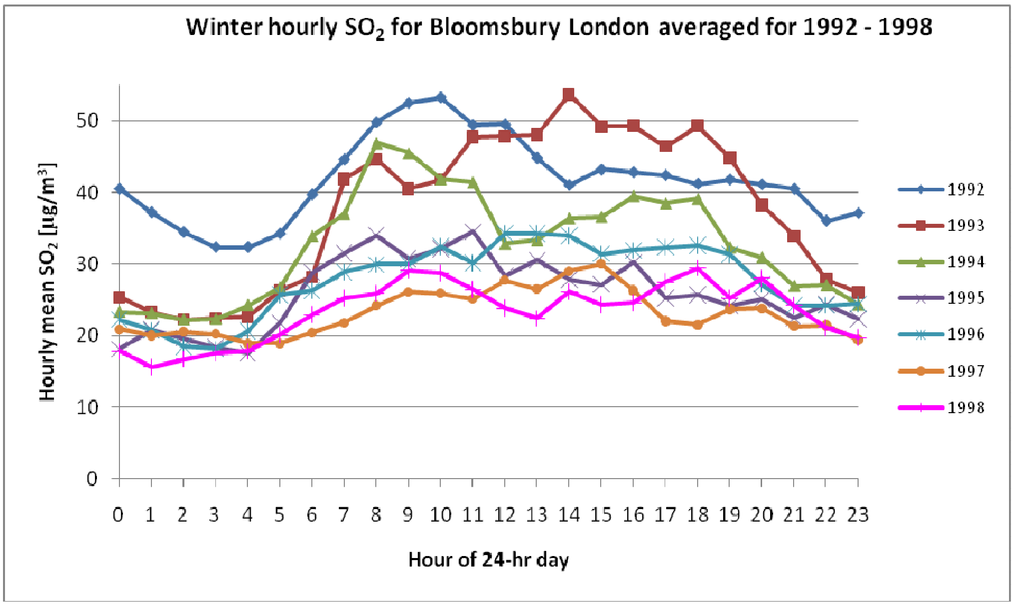


Figure 15 – Diurnal plot of winter hourly SO_2 for an urban background station in London 1992-1998

Figure 16 present diurnal SO_2 plots by season for an urban background station (Nea Smyrni) in Athens for the years 1994 and 2000. In both years there is a pronounced peak in the morning hours which is most likely due to traffic related emissions during the morning rush hour. Furthermore there is a less pronounced peak in the evening hours (8pm to 11pm) that most likely reflects the evening rush hour as well as space heating especially notable for the winter plots. SO_2 levels are markedly lower during spring and summer than in the colder months where emission from central heating are added to those from the other sources. Overall comparing the two years of 1994 and 2000 a decrease in SO_2 levels overtime has been observed especially in the cold season and on a lower scale in the warm seasons.

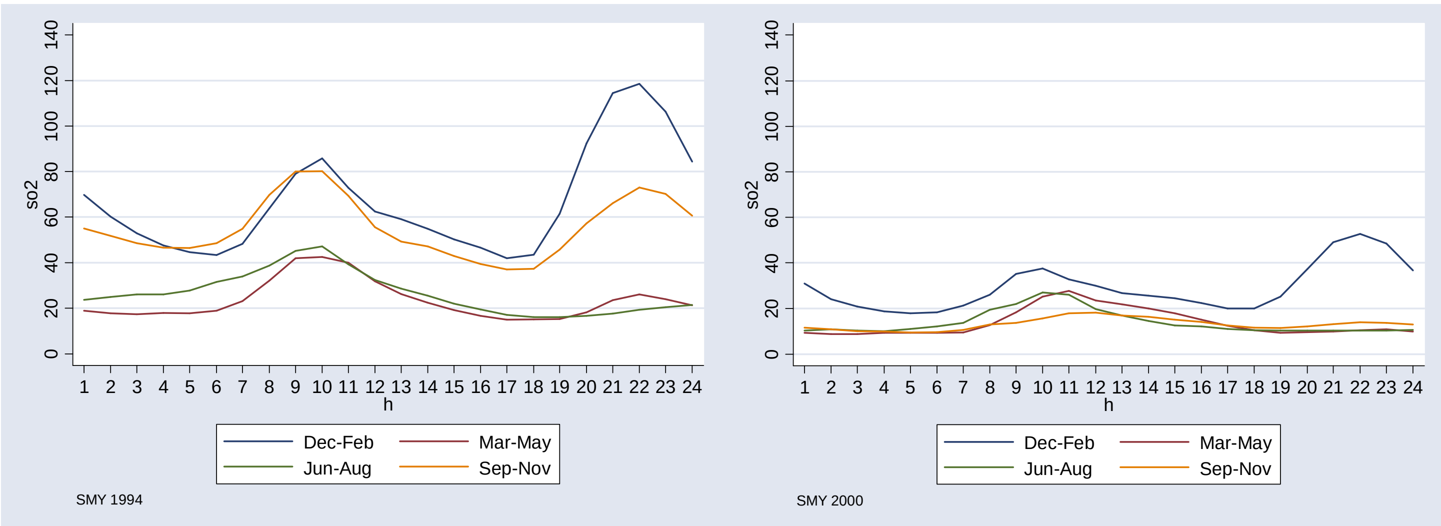


Figure 16 – Diurnal plot of hourly SO_2 for an urban background station in Athens in 1994 and 2000, by season.

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-analytic 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. 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 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.

Chapter 5. Overview of findings and local recommendations

Across the 25 European cities the benefits of improving air quality are impressive both in terms of benefits in human health and in monetary savings, although uncertainties are still present in these estimations. Reducing levels of $PM_{2.5}$ fine particles to WHO's annual air-quality guideline could add up to an additional 22 months of life expectancy for persons 30 years of age, depending on the city and its average level of $PM_{2.5}$. Aphekom also determined that the monetary health benefits from complying with the WHO guideline would equal about €31.5 billion annually, including savings on health expenditures, absenteeism and intangible costs such as well being, life expectancy and quality of life

In the cities studied, HIA showed that living near busy 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. An economic burden of more than €300 million per year, attributable to chronic diseases, is caused by living near heavy traffic.

Concerning the efficiency of EU directives on air quality, 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.

Athens is among the cities with the highest PM concentrations within Aphekom and has difficulty in reaching the EU regulated standards for both PM_{10} and ozone. Due to the topography and climate, relatively low level of emission results in relatively high air pollution concentrations. Reduction of the pollutant levels to the EU standards will prevent a considerable number of premature deaths which is linked to avoided costs. Although in recent years there is a declared policy to reduce the use of private cars and improve the quality of fuel, actions for improving air quality should intensify and added to the climate change action plan in order to achieve a greater efficiency and to reduce negative outcomes.

Acknowledgements

Hellenic Statistical Authority
Ministry of Environment, Energy and Climate Change; Division of Air Pollution and Noise Control (PERPA)

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 1 – Health outcome and relative risks used in the HIA

HIA	Health outcome	Ages	RR per 10 µg/m^3	Ref
Short-term impacts of PM_{10}	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 $PM_{2.5}$	Non-external mortality	>30	1.06 [1.02-1.11]	(7)
	Cardiovascular mortality	>30	1.12 [1.08-1.15]	(8)

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 same PM_{10} annual mean is decreased to 20µg/m^3, the WHO air quality guideline (WHO-AQG).
The exposure indicator of PM_{10} 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, $\Delta x = ([PM_{10}]_{mean} - 20\ \mu g/m^3)$.
  $\Delta x = 0$ if $[PM_{10}]_{mean} < 20$

Ozone

For ozone, WHO set two values for the daily maximum 8-hours mean. The interim target value (WHO-IT1) is set at 160µg/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 160µg/m^3 were reduced to WHO-IT (160 µg/m^3), then a scenario where all daily values above 100µg/m^3 were reduced to WHO-AQG (100 µg/m^3), and lastly a scenario where the daily mean is decreased by 5µg/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 5µg/m^3. $\Delta x = 5\ \mu g/m^3$

$PM_{2.5}$

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 annual AQG).
The exposure indicator of $PM_{2.5}$ 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, $\Delta x = ([PM_{2.5}]_{mean} - 10\ \mu g/m^3)$
  $\Delta x = 0$ if $[PM_{2.5}]_{mean} < 10$

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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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