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Aphekom

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

Local city report

Roma, Italy

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Risultati principali del progetto Aphekom

Diversi studi epidemiologici hanno mostrato una associazione tra inquinamento dell'aria e stato di salute dei residenti a Roma, ma finora non era disponibile una valutazione dell'impatto sanitario (VIS).

E' stato valutato l'impatto sulla salute e l'impatto finanziario relativo agli effetti dell'esposizione a lungo e breve termine ad inquinamento dell'aria a Roma nel periodo 2004-2006 seguendo la metodologia del progetto Aphekom. Lo studio si basa su dati di inquinamento dell'aria forniti da ARPA-Lazio e dall'Istituto Superiore di Sanità e sui dati sanitari del Sistema Informativo Sanitario regionale. E' stato utilizzato un approccio geografico per stimare l'impatto che il vivere in prossimità di strade ad alto traffico ha sulla salute.

Durante i tre anni in studio la concentrazione media annuale di polveri fini (PM10) è stata di 39 $\mu g/m^3$, entro il limite di legge (40 $\mu g/m^3$), ma al di sopra delle linee guida dell'Organizzazione Mondiale di Sanità-OMS (20 $\mu g/m^3$); la media del valore massimo della media mobile a otto ore della concentrazione di ozono (O3) è stata di 73 $\mu g/m^3$ entro le linee guida OMS (100 $\mu g/m^3$); la concentrazione media annuale di PM2.5 (21 $\mu g/m^3$) è diminuita dal 2004 al 2006, ma è ancora sopra le linee guida OMS (10 $\mu g/m^3$).

La VIS ha utilizzato due scenari per valutare i benefici della riduzione di PM_{10}, ozono e $PM_{2.5}$: una riduzione di 5 $\mu g/m^3$ e la riduzione fino ai livelli delle linee guida OMS. Il PM_{10} e l'ozono sono stati usati per valutare gli effetti a breve termine dell'esposizione ad inquinamento dell'aria e il PM2.5 è stato utilizzato per valutare gli effetti a lungo termine dell'esposizione.

La tabella seguente riassume i risultati principali per le polveri sospese

Tabella. Risultati principali

	Effetti a breve termine PM10		Effetti a lungo termine PM2.5	
	riduzione di 5 $\mu g/m^3$	riduzione a 20 $\mu g/m^3$ (linee-guida OMS)	riduzione di 5 $\mu g/m^3$	riduzione a 10 $\mu g/m^3$ (linee-guida OMS)
Mortalità				
Anni di vita guadagnati a 30 anni			0.4	1.0
Numero annuale di morti per cause cardiovascolari evitabili			471	997
Numero annuale di morti per cause naturali evitabili	61	227	594	1278
Guadagno economico (milioni di euro)	5,3	19,7	983,1	2115,1
Ospedalizzazioni per malattie respiratorie				
Numero annuale di casi evitabili	158	579		
Guadagno economico (milioni di euro)	0,6	2,3		
Ospedalizzazioni per malattie cardiache				
Numero annuale di casi evitabili	118	434		
Guadagno economico (milioni di euro)	0,5	1,7		

Con una riduzione di 5 µg/m^3 della concentrazione media di ozono si eviterebbero 32 morti, 31 ricoveri di anziani per malattie cardiache e 5 ricoveri nella popolazione di 15-64 anni per malattie respiratorie. L'impatto monetario stimato delle morti evitate è di €2,771,200.

Summary

Several epidemiological studies have already described the association between air pollution and health effects in Rome, but a comprehensive Health Impact Assessment (HIA) was not yet available. We have evaluated the short and long-term health and monetary impact of air pollution in Rome during the period 2004-2006 following the Aphekom methodology. Air pollution data were collected from the Regional Environmental Protection Agency and from the National Health Institute while statistics on mortality and hospitalizations were collected from the regional health information system. A Geographic Information System (GIS) approach was used to estimate the air pollution health impact for people living close to roads with intense traffic.

During the study period, the annual average PM_{10} value (standard deviation, SD) was 39 (15) µg/m^3, above the World Health Organization (WHO) Air Quality Guidelines (20 µg/m^3), but under the standard limit established by law (40 µg/m^3). For the summer period of the three years, the average (SD) of maximum daily 8-hour moving average concentration of ozone (O3) was 73 (38) µg/m^3 ranging from 13 to 133 µg/m^3 (WHO Air Quality Guideline, 100 µg/m^3). The annual average $PM_{2.5}$ concentration was 21 (12) µg/m^3 (WHO Air Quality Guideline, 10 µg/m^3), decreasing from 23 (13) µg/m^3 in 2004 to 20 (11) µg/m^3 in 2006.

At city level, the annual mean number of deaths was 20,574 (732 per 100,000 inhabitants), 8,548 for cardiovascular causes (417 per 100,000 inhabitants), the hospitalization rate for respiratory diseases was 994 per 100,000 and for cardiac diseases was 1,402 per 100,000.

The health impact assessment used two scenarios to evaluate the annual benefits of reducing PM_{10}, ozone and $PM_{2.5}$: reduction of 5 µg/m^3 and reduction to the levels recommended by the WHO Air Quality Guidelines. PM_{10} and ozone were considered for the short term effects while $PM_{2.5}$ was considered for long-term effects.

Reducing annual mean PM_{10} concentration by 5 µg/m^3, 61 deaths, 158 hospitalizations for respiratory conditions and 118 hospitalizations for cardiac diseases would be avoided each year in the general population. Reducing annual mean PM_{10} concentration to 20 µg/m^{3,} 227 deaths, 579 hospitalizations for respiratory conditions and 434 hospitalizations for cardiac diseases would be avoided annually in the general population.

Reducing annual mean ozone concentration by 5 µg/m^3, 32 deaths, 31 hospitalizations for cardiac diseases in the elderly population and 5 respiratory hospitalizations in population aged 15-64 years would be avoided each year.

Reducing annual mean $PM_{2.5}$ concentration by 5 µg/m^3, 594 natural deaths and 471 cardiovascular deaths would be avoided each year in the general population, with a gain in life expectancy in those aged 30 years of 0.4 years. Reducing annual mean $PM_{2.5}$ concentration to 10 µg/m^3, 1,278 natural deaths (997 for cardiovascular diseases) would be avoided annually in the general population with a gain in life expectancy of one year for those now aged 30 years.

The estimated monetary gain of short term impacts of reducing by 5 µg/m^3 the annual mean PM_{10} and ozone concentrations is €5,282,600 and €2,771,200, respectively. The estimated monetary gain that could be obtained from long term impacts of reducing by 5 µg/m^3 the annual mean of $PM_{2.5}$ concentration is €983,070,000 per year, while decreasing the annual level of $PM_{2.5}$ to 10 µg/m^3 is €2,115,090,000.

A total of 23% of citizens in Rome live close (75 meters) to a busy road and the percentage is higher when considering 150 meters (43%). The study estimates that among those living close to busy roads, 11% of exacerbations of asthma in children, 18% of acute worsening of Chronic Pulmonary Obstructive Diseases (COPD) and 23% of acute problems related to coronary heart diseases (CHD) in elderly (65+ years) are attributable to the local hot-spots of air pollution.

The results of the study, with the example of the city of Rome, highlights the importance of national and local programs to reduce air pollution and its health impact.

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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

CHD: coronary heart diseases

COPD: Chronic Pulmonary Obstructive Diseases

HIA: health impact assessment

O3 : ozone

PM10 : particulate matter with an aerodynamic diameter <10 µm

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

VOLY: Value of Life Year

VSL: Value of a Statistical Life

WHO: World Health Organization

Introduction

The health effects of air pollution have been well described and the scientific literature has indicated that particulate matter as well as gases are related to short-term, acute, effects occurring from hours to few days since exposure. However long-term chronic exposures may also lead to chronic health conditions with increased morbidity and mortality. A comprehensive review of the literature has been conducted by an authoritative scientific group appointed by the European Respiratory Society and it is available online in different languages, including English and Italian (1).

The health consequences of air pollution in Rome have been extensively studied with regard to short term effects on mortality (2-6); hospitalizations (7-9), and lung function decrements (10). Also long-term effects have been highlighted using modern techniques to evaluate spatial air pollution levels, in particular long term effects on lung function in children (11) and incidence of coronary ischemic heart diseases (12). A large longitudinal cohort study is currently on going to better evaluate the overall air pollution impact (13). Finally, A national program funded by the Ministry of Health (EpiAir, http://www.epiair.it/) is continuously monitoring the health effects of air pollution in several cities, including Rome.

Although the epidemiological effort has been large, a comprehensive health impact assessment has not been conducted. Such an evaluation would inform policy makers and citizens of the potential benefit of policies of a better air quality. In fact, 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 (HIA) have been used to analyze the impact of improving air quality on the health status of a given population. Using standardised HIA methods, the preceding Apheis project (14) (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 (15-16). Apheis thus confirmed that, despite reductions in air pollution since the 1990s, the public health burden of air pollution remains of concern in Europe.

A preliminary assessment within the previous Apheis project in Rome showed that reducing PM_{10} daily mean values to 20 $\mu g/m^3$ would prevent 181 hospital respiratory admissions in children below 15 years, a reduction of 10 $\mu g/m^3$ in the daily maximum 8-hour moving concentrations of ozone would delay 31.3 deaths per year in the general population (19 from cardiovascular diseases, 6 from respiratory causes).

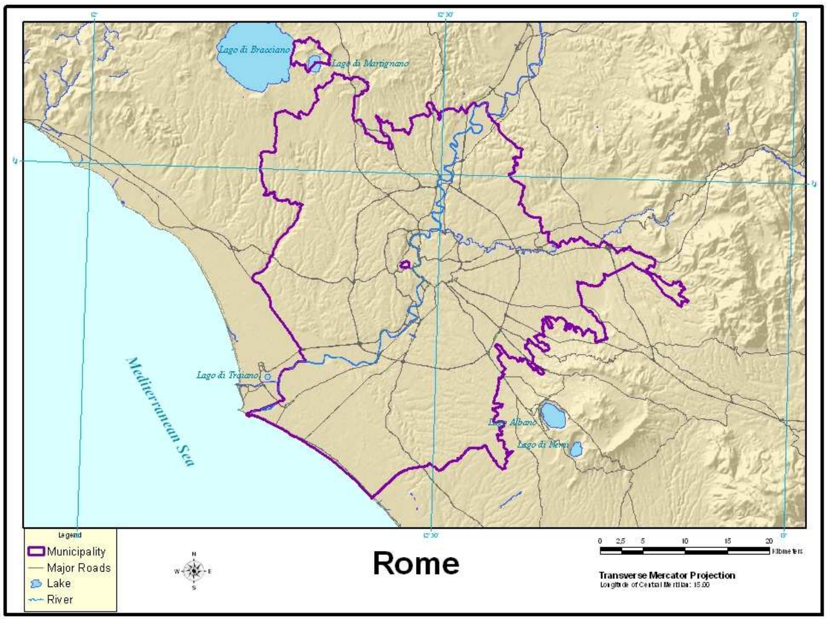
Building on the experience gained in the earlier Apheis project, Aphekom conducted a standardised HIA of urban air pollution in the 25 Aphekom cities totalling nearly 39 million inhabitants: Athens, Barcelona, Bilbao, Bordeaux, Brussels, Bucharest, Budapest, Dublin, Granada, Le Havre, Lille, Ljubljana, 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 Rome

The data used in this report were provided by the Regional Environmental Protection Agency and by the Municipality of Rome.

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

Figure 1 – Map of the study area



Climatology

Rome has a Mediterranean climate, with warm spring and autumn. During the our study period, the daily mean summer temperature (about three months: from June to August) did not exceed the 30℃ (in 2006: Mean 15.8, SD 7.2℃ Min 1.6℃ Max 29.3℃) , while the daily mean winter (about three months: from December to February) temperature was close to 15℃ (in 2006: Mean 7.56℃, SD 3.01℃ Min 1.6℃ Max 14.8℃). The overall annual me an value of temperature was about 15/16 ℃. The average relative humidity (75.5%) was reduced from 77% in 2004 to 74% in 2006, and the average winter rainfalls were reduced from 2.8 mm in 2004 to 1.7 in 2006. The winds had an average direction of 161° and a speed of 2.4 m/s.

Population in the study area

Rome is the national capital and it is the largest Italian city with a population of 2.8 million inhabitants on a surface of 1290 km^2. In Rome 21% of population is aged 65 years or more, while only 13% is under 15 years of age. Given the urbanization history of the city, the population density is higher in the city centre than in the periphery (6,739 vs. 783 inhabitants per squared kilometre).

1.2. Sources of air pollution and exposure data

Sources

Air pollution in Rome originates primarily from motor vehicle traffic and domestic heating, while the contribution of industrial plants is small (higher for SOx). According to data from the Italian Institute for Environmental Protection and Research, 80% and 52% of NOx and PM_{10} emissions respectively are due in Rome to motorized road traffic. Table 1 shows the main sources of air pollution in 2000.

Table 1 – Main sources of air pollution (expressed as tons/year)

Pollutant	Road	Heating	Industry	Other sources (transportation other than road, incineration of waste…)
SO_x	522.90	757.39	2586.05	393.55
NO_x	33073.57	3154.69	930.62	3430.17
Primary PM_{10}	2235.68	757.39	190.74	510.15

Exposure data

Air pollution data were provided by the Regional Environmental Protection Agency. Among all the monitors in Rome, PM_{10} was available from three monitors (Villa Ada - urban background site, Magna Grecia – traffic site, and Arenula – residential site), Ozone was available from two monitor stations (Villa Ada - urban background site, and Largo Preneste – residential site).

During the study period data on particulate matter with an aerodynamic diameter lower than 2.5 microns ($PM_{2.5}$) were not regularly monitored by the Regional Environmental Protection Agency, therefore we used a monitoring station 2 km east of the city center on the grounds of the Italian National Institute of Health (NIH). The measurement method for $PM_{2.5}$ follows the standards set in 2005 (Comitè Européen de Normalisation 2005).

PM_{10} was measured using a β-gauge method. $PM_{2.5}$ was measured with gravimetric method. Ozone was measured using ultra-violet ray absorption.

The daily exposure to PM_{10} was calculated as the arithmetic mean of the daily concentrations of the three stations. In case of missing values on a specific day and monitoring station we imputed that value with the average of measurements of the pollutant for that day across the other monitors, weighted by the ratio of the yearly average of that monitor over the yearly average of all others. The daily maximum 8-hour moving averages of daily ozone was calculated for the study period.

Table 2 shows the daily mean levels with standard deviation and the 5^{th} and 95^{th} percentiles of the distribution of air pollutants.

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

Pollutant	**Daily mean (μg/m^3)**	**Standard deviation (μg/m^3)**	***5^{th} percentile* (μg/m^3)**	***95^{th} percentile* (μg/m^3)**
Ozone (daily 8h max)	73	38	13	133
PM10 (daily avg)	39	15	19	67
PM2.5 (daily avg)	21	12	8	45

Figure 2 shows the average daily concentration of Ozone in Rome. O_3 levels varied over the three years with peaks in the summer periods. Figure 3 shows the variability of PM10 and Figure 4 the variability of $PM_{2.5}$ daily concentrations, here the highest levels of concentration are during the winter periods.

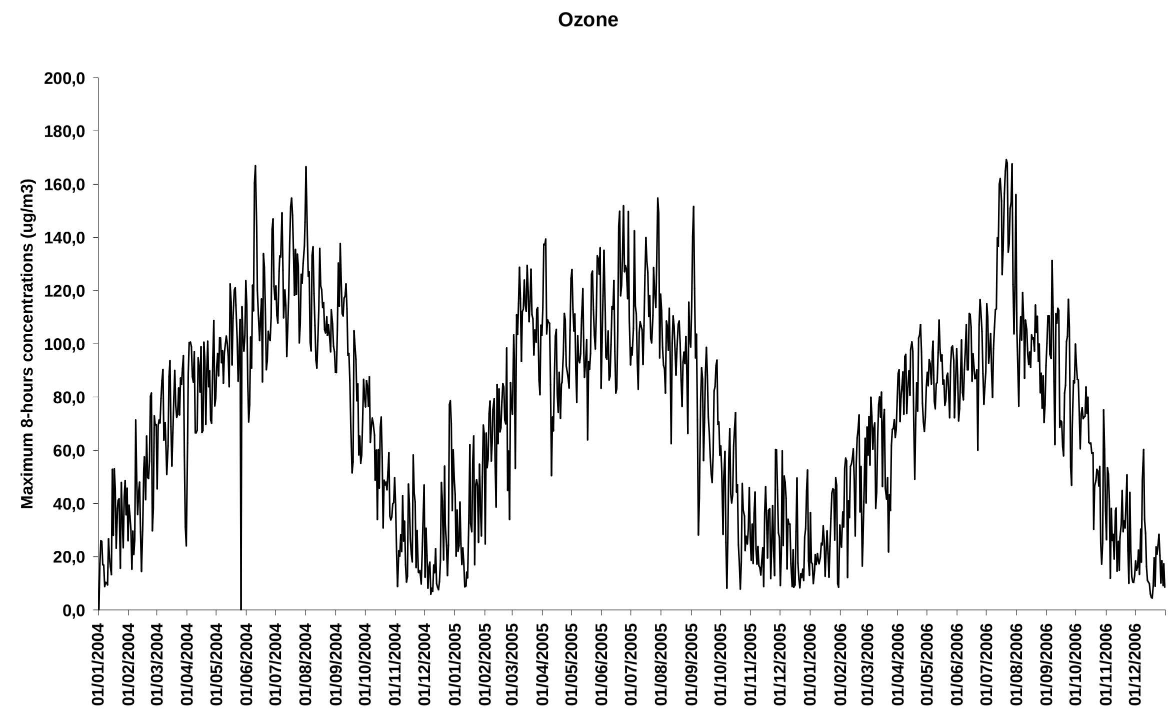


Figure 2 – Ozone concentration in the study area

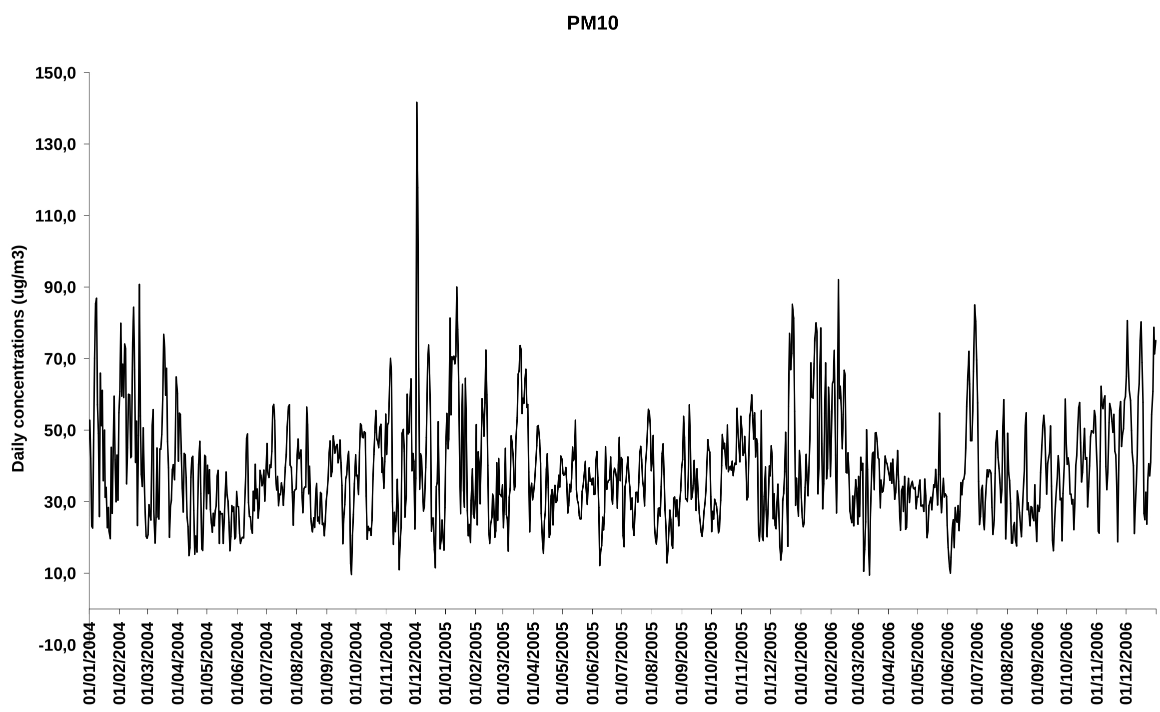


Figure 3 – PM10 concentration in the study area

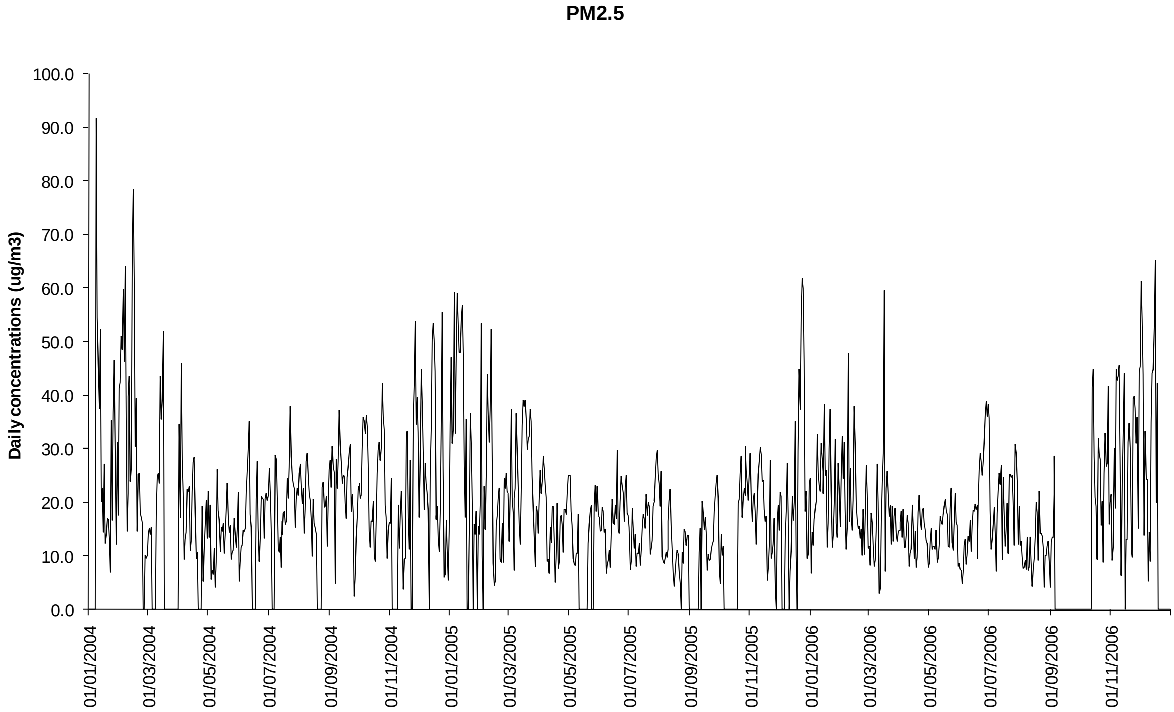


Figure 4 – PM2.5 concentration in the study area

1.3. Health data

This study is based on information from the Health Information System of the Lazio region, where Rome is located. The Regional Cause of Death Registry lists the underlying causes of death coded according to the International Classification of Diseases, 9th Revision, for all deaths of residents of the Lazio region. Discharge abstracts, from both public and private hospitals, are routinely collected by the Regional Information System and contain: patient demographic data (gender, age, place of birth, census block of residence for residents of Rome), admission and discharge dates, up to 6 discharge diagnoses (International Classification of Disease, 9th Revision, Clinical Modification [ICD-9-CM]), medical procedures or surgical interventions (up to 6), and status at discharge (alive, dead, transferred to another hospital).

The percentage of missing data for cause of death is less than 0.1%. Since we were interested in both short and long-term effects of air pollution on mortality, we selected all the deaths of residents occurred in the city of Rome (89% of all deaths of residents). Since Hospital funding is based on Regional Information System, it includes 96% of all discharges (100% of those from public hospitals). The percentage of missing principal diagnosis is less than 0.1%.

During the period 2004-2006 the annual mean number of deaths occurred in Rome was 20,574. The annual non external mortality rate of was 732 per 100,000, and the mortality rate for cardiovascular diseases in adult population (> 30 years of age) was 417 per 100,000.

There were 39,385 annual hospitalizations for cardiac diseases (1,402 per 100,000), and 27,910 annual hospitalizations for respiratory diseases (994 per 100,000). In the population aged 15-64 years the mean annual rate for respiratory hospitalizations was 349 per 100,000 while in the elderly population (>=65 years) it was 450 per 100,000.

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*	001 – 799	A00-R99	All	20574	732
Non-external mortality	001 – 799	A00-R99	> 30		
Cardiovascular mortality	390-459	I00-I99	> 30	8548	417
Cardiac hospitalizations	390-429	I00-I52	All	39385	1402
Respiratory hospitalizations	460-519	J00-J99	All	27910	994
Respiratory hospitalizations	460-519	J00-J99	15-64 yrs	9807	349
Respiratory hospitalizations	460-519	J00-J99	≥ 65 yrs	12629	450

*** 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 PM_{10}, we first considered a scenario where the annual mean of PM_{10} is decreased by 5 µg/m^3, and then a scenario where the PM_{10} annual mean is decreased to 20 µg/m^3, the WHO annual air quality guideline (WHO-AQG).

Reducing annual mean of PM_{10} by 5 µg/m^3 would postpone 61 deaths for natural causes per year (2 deaths per 100,000), while decreasing PM_{10} to 20 µg/m^3 would postpone 227 deaths per year (8 deaths per 100,000) (Table 4).

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

Scenarios	Total annual number of deaths postponed	Annual number of deaths postponed per 100 000
Decrease by 5 µg/m^3	61	2
Decrease to 20 µg/m^3	227	8

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

Table 5 shows the potential benefits on respiratory and cardiac hospitalizations. Reducing annual mean of PM_{10} by 5 µg/m^3 would avoid 158 annual respiratory hospitalizations and 118 cardiac hospitalizations. Decreasing PM_{10} to 20 µg/m^3 would avoid 579 respiratory hospitalizations and 434 cardiac hospitalizations.

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

	Respiratory hospitalisations		**Cardiac hospitalisations**	
Scenarios	**Total annual number of cases postponed**	**Annual number of cases postponed per 100 000**	**Total annual number of cases postponed**	**Annual number of cases postponed per 100 000**
Decrease by 5 µg/m^3	158	6	118	4
Decrease to 20 µg/m^3	579	21	434	15

Figure 5 shows the benefits in the general population, under the two scenarios, on natural mortality, hospitalizations for respiratory and cardiac diseases.

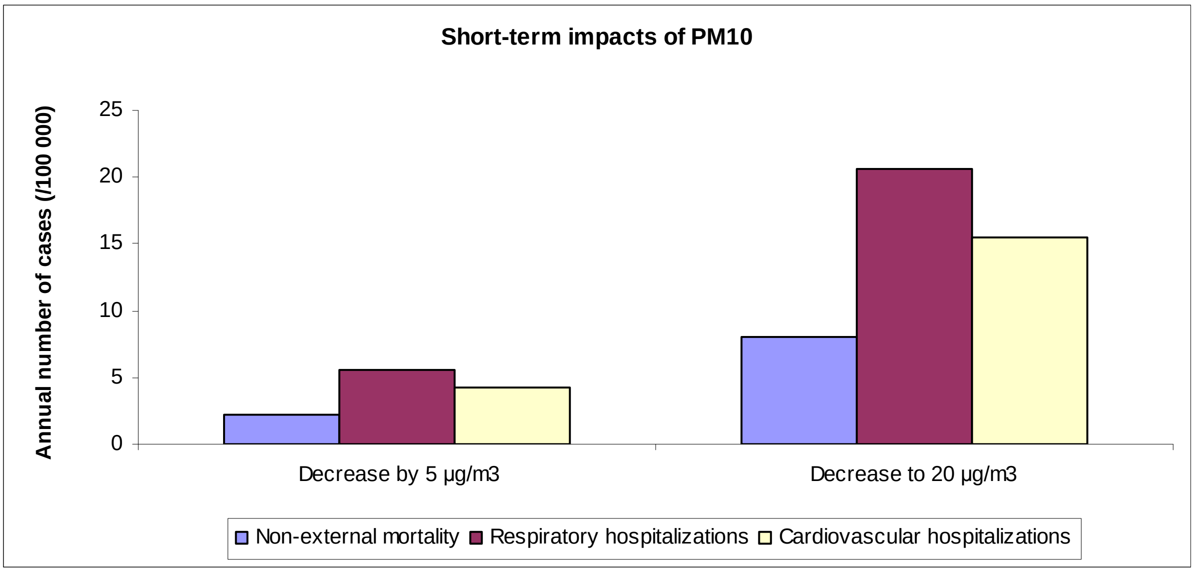


Figure 5 – Potential benefits of reducing annual PM10 levels on mortality and on hospitalisations

1.4.2. Short-term impacts of ozone

For ozone, WHO set two guideline values for the daily maximum 8-hour 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.

Reducing by 5 µg/m^3 the daily mean of ozone concentration would postpone 32 deaths per year in the general population (Table 6), 5 respiratory hospitalizations in the population aged 15-64 years, and 31 cardiac hospitalizations in residents aged 65 years and more (Table 7). Similar results would be obtained if all daily values above 100 µg/m^3 were reduced to WHO-AQG (100 µg/m^3) (Figure 6).

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

Scenarios	Total annual number of deaths postponed	Annual number of deaths postponed per 100 000
8h max daily values >160 µg/m^3 = 160 µg/m^3	0	0
8h max daily values >100 µg/m^3 = 100 µg/m^3	32	1
Decrease by 5 µg/m^3	32	1

***Non-external mortality excludes accidental deaths.**

Table 7 – 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	5	0	31	5
Decrease by 5 µg/m^3	5	0	31	5

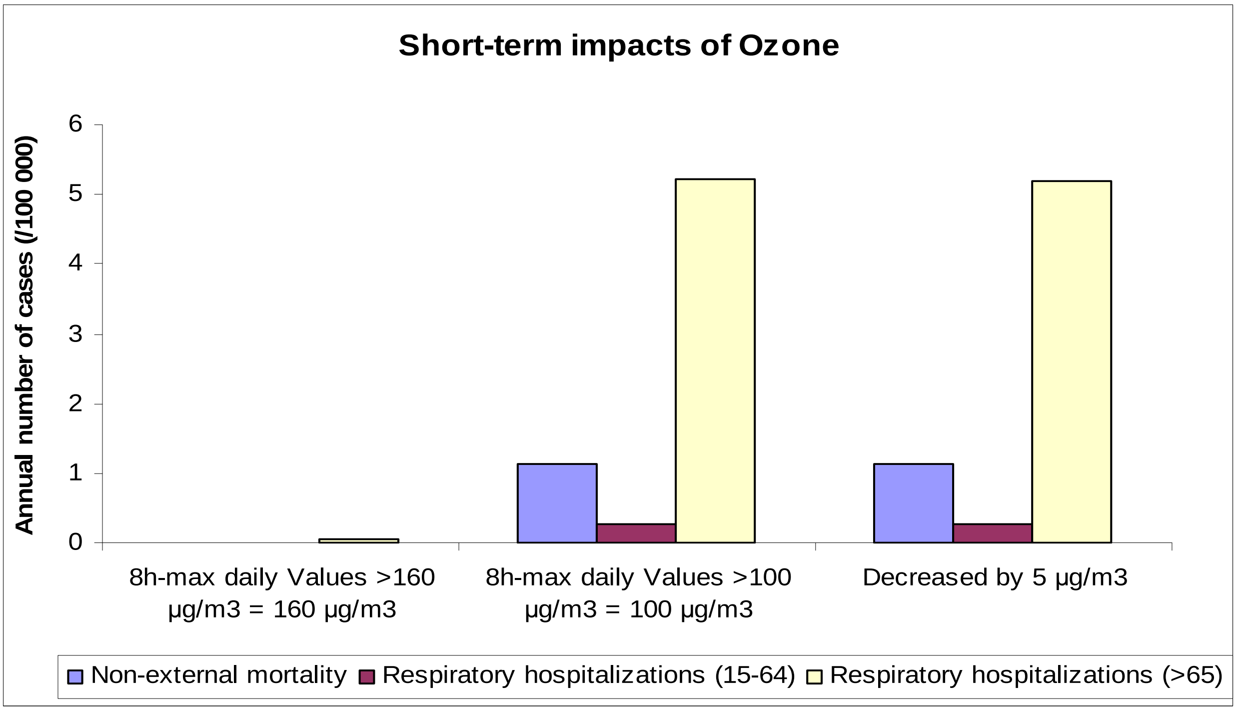


Figure 6 – Potential benefits of reducing daily ozone levels on mortality and on hospitalisations

1.4.3. Long-term impacts of PM2.5

For $PM_{2.5}$, we first considered a scenario where the $PM_{2.5}$ annual mean is decreased by 5 µg/m^3, and then a scenario where the $PM_{2.5}$ annual mean is decreased to 10 µg/m^3 (WHO AQG).

The potential long-term impacts of reducing $PM_{2.5}$ on non-external mortality and life expectancy are shown in Table 8. Decreasing $PM_{2.5}$ by 5 µg/m^3 would postpone 594 deaths per year in the general population (29 deaths per 100,000) with a gain in life expectancy of 0.4 years in the general population. Reducing annual mean of $PM_{2.5}$ to 10 µg/m^3 would have a much stronger impact, postponing 1278 deaths (62 per 100,000), with a gain in life expectancy of one year.

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

Scenarios	**Total annual number of deaths postponed**	**Annual number of deaths postponed per 100 000**	**Gain in life expectancy**
Decrease by 5 µg/m^3	594	29	0.4
Decrease to 10 µg/m^3	1278	62	1.0

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

The potential long-term impacts of reducing $PM_{2.5}$ on cardiovascular mortality are presented in Table 9. Decreasing $PM_{2.5}$ by 5 µg/m^3 would postpone 471 cardiovascular deaths per year in the general population (23 deaths per 100,000). Reducing annual mean of $PM_{2.5}$ to 10 µg/m^3 would have a much stronger impact, postponing 997 deaths (49 per 100,000).

Table 9 – 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	471	23
Decrease to 10 µg/m^3	997	49

Figure 7 summarizes the potential benefits of the two scenarios on natural and cardiovascular mortality.

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

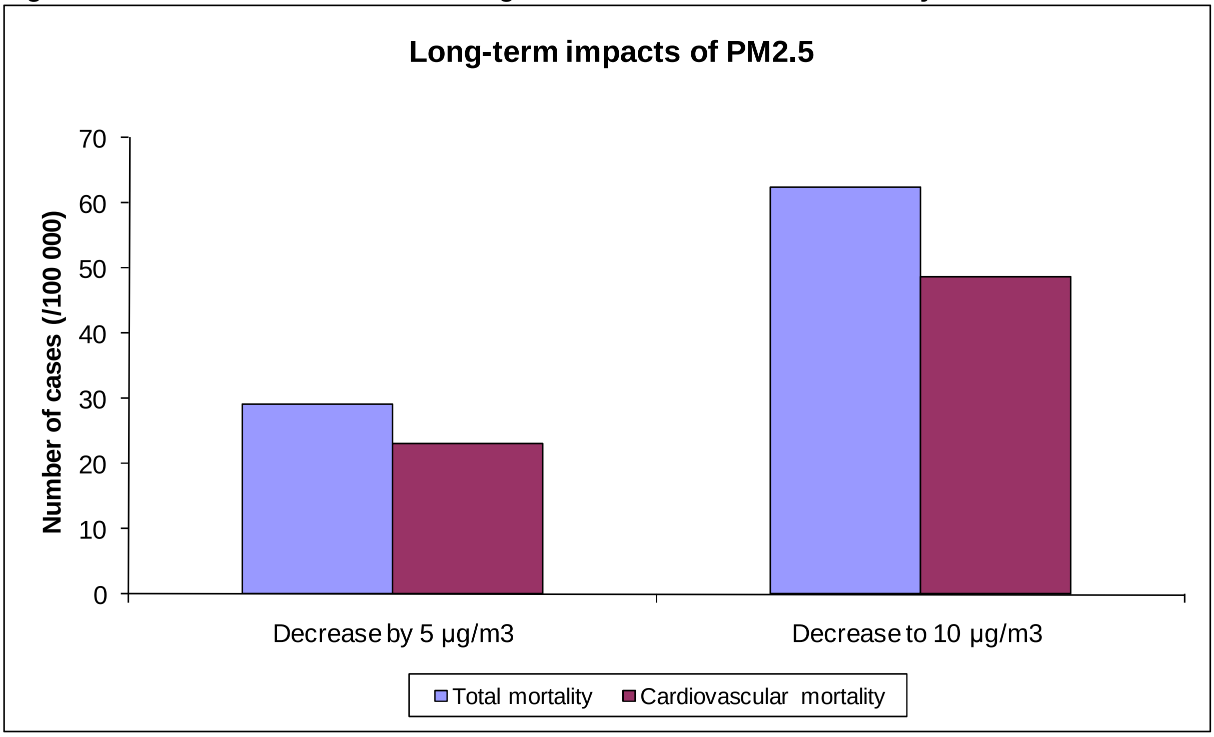
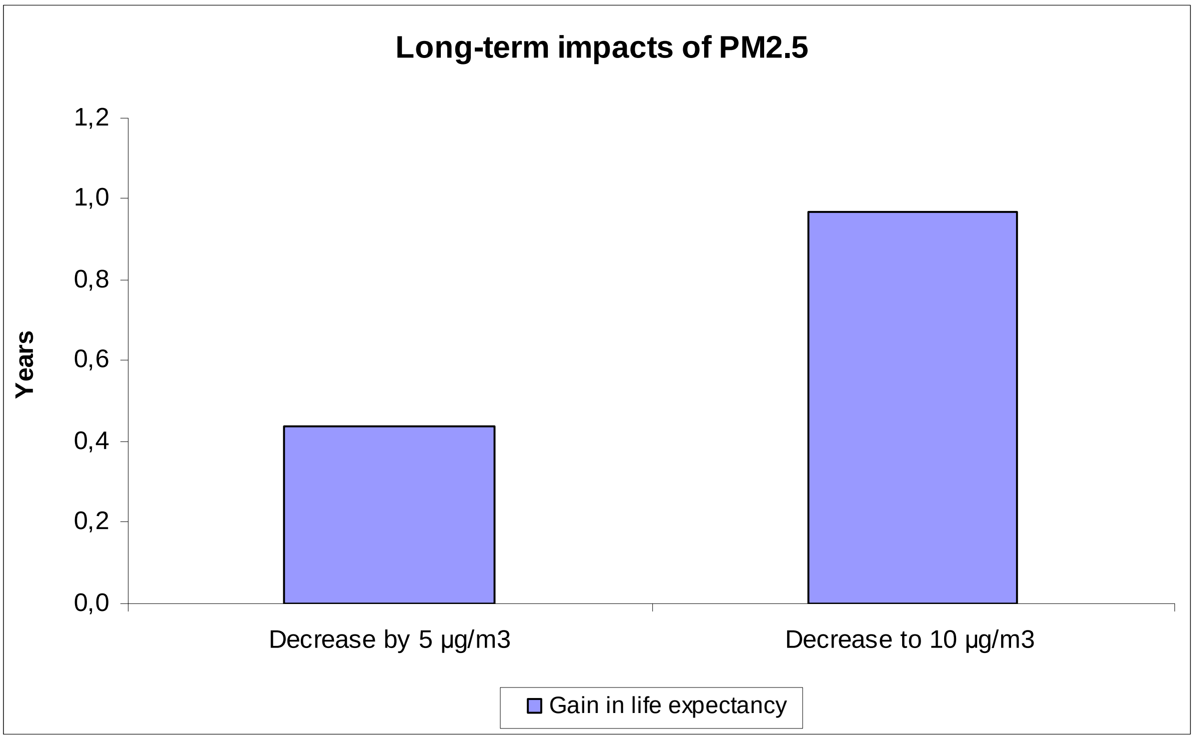


Figure 8 summarizes the potential benefits of the two scenarios on life expectancy.

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 differ depending on the short- or long-term nature of the exposure to air pollution (see Appendix 2).

The monetary gain of short term impacts of reducing by 5 µg/m^3 the annual mean of ozone concentration could be €2,771,200, and the monetary gain of short term impacts in reduction by 5 µg/m^3 the annual mean of PM_{10} could be €5,282,600.

The monetary gain that could be obtained from long term impacts is €983,070,000 per year with a reduction the annual mean of $PM_{2.5}$ concentration by 5 µg/m^3, and €2.1 billion with a reduction to 10 µg/m^3.

The monetary gain due to the gain in life expectancy obtained by decreasing the annual level of $PM_{2.5}$ to 10 µg/m^3 would be €86,600 multiplied by the number of residents aged 30 years (34,762 subjects) and by the gain in life expectancy (0.97 years): €3 billion. 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 $PM_{2.5}$ (WHO's Air Quality Guideline) instead of the current existing air pollution level in Rome. Similarly the benefits (in term of life expectancy) 30 year-old people would gain over their lifetime if exposed to 16 µg/m^3 average annual level of $PM_{2.5}$ (the actual mean level decreased by 5 µg/m^3) would be €1.2 billion.

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 (see Appendix 2).

With a decrease by 5 µg/m^3 in the annual mean of PM_{10} the economic benefit given by the postponement of hospitalizations would be of €457,026 (from cardiac causes) and € 635,792 (from respiratory causes) in each year. The benefits of reducing the annual mean of PM_{10} to 20 µg/m^3 would be €1,680,925 from cardiac hospitalizations and €2,329,896 from respiratory hospitalizations.

1.4.5. Interpretation of findings

Using traditional health impact assessment methods, Aphekom has shown that a decrease in annual mean PM_{10} concentration by 5 µg/m^3 could have strong short-term impacts on health avoiding 61 deaths, 158 hospitalizations for respiratory conditions and 118 hospitalizations for cardiac diseases. The long-term impact that could be obtained by reducing annual mean $PM_{2.5}$ concentration by 5 µg/m^3 would be 594 avoided natural deaths and 471 cardiovascular avoided deaths in each year, with a gain in life expectancy in those aged 30 years or more of 0.4 years. The health impact that could be obtained decreasing annual average of PM_{10} of 20 µg/m^3 or annual average of $PM_{2.5}$ to 10 µg/m^3 would be much greater with enormous economic benefits.

The results presented in this report have some limitations.

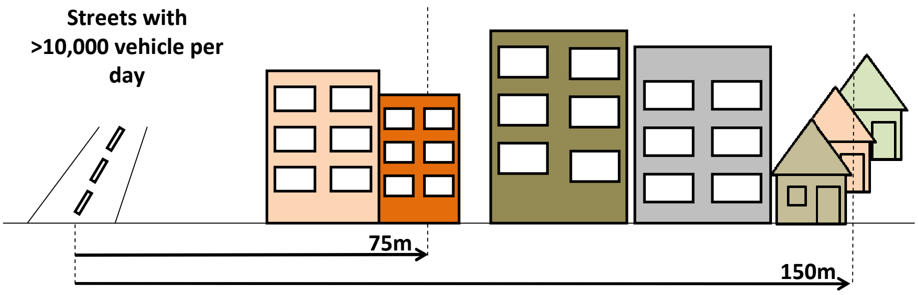
In the long term impact assessment the $PM_{2.5}$ data come from only one monitoring station, however the data from the Regional Environmental Protection Agency who systematically measured $PM_{2.5}$ data since the second part of 2006 confirm the trend presented here. For long term evaluation impacts the deaths of residents in Rome occurred outside the municipality should have been considered. We used concentration response functions derived in the US for the association between air pollution with both natural and cardiovascular mortality. There are not available studies with local concentration response functions, however there are studies which analysed the association between nitrogen dioxide exposure and mortality, and the results were comparable to the American literature.

Chapter 2. Health Impacts and Policy: Novel Approaches

Pollutants such as ultrafine particles occur in high concentrations along streets and roads carrying heavy traffic. 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.

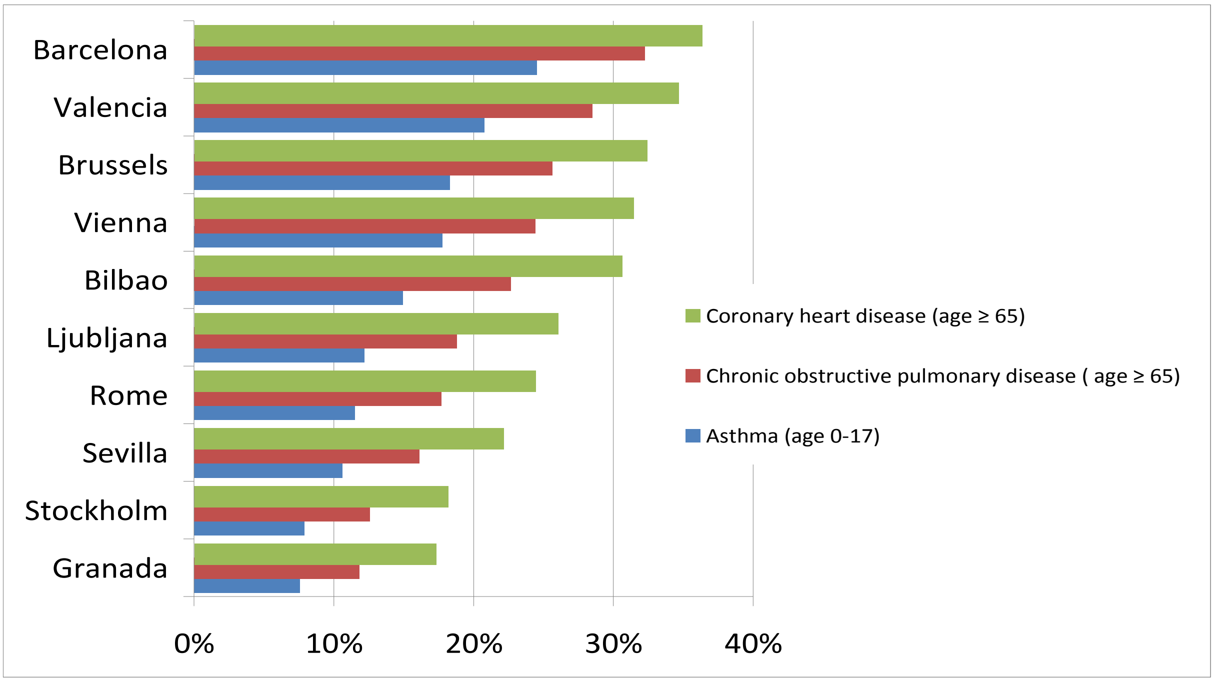


Figure 10 – Percentage of population with chronic diseases whose disease is attributable to living near busy streets and roads in 10 Aphekom cities

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.

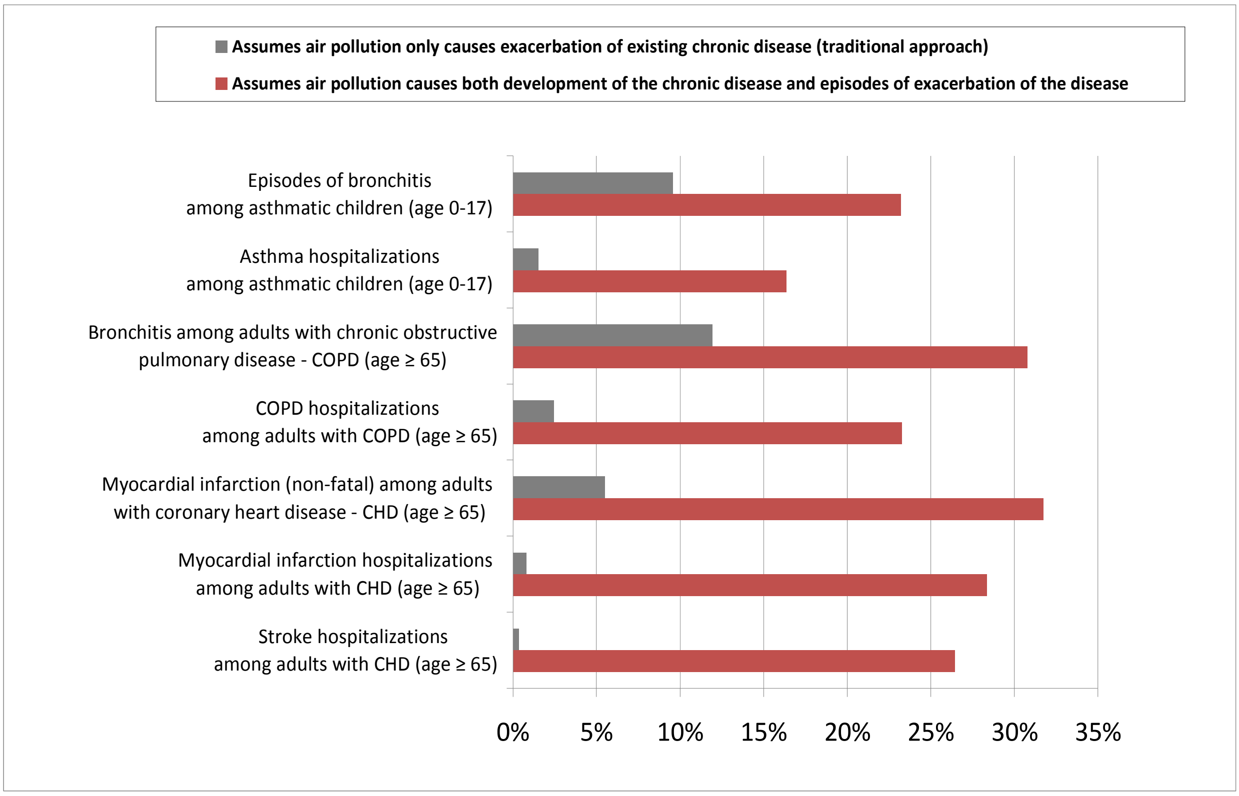


Figure 11 – Comparison of impact of air pollution on chronic diseases calculated using two different HIA approaches in Aphekom

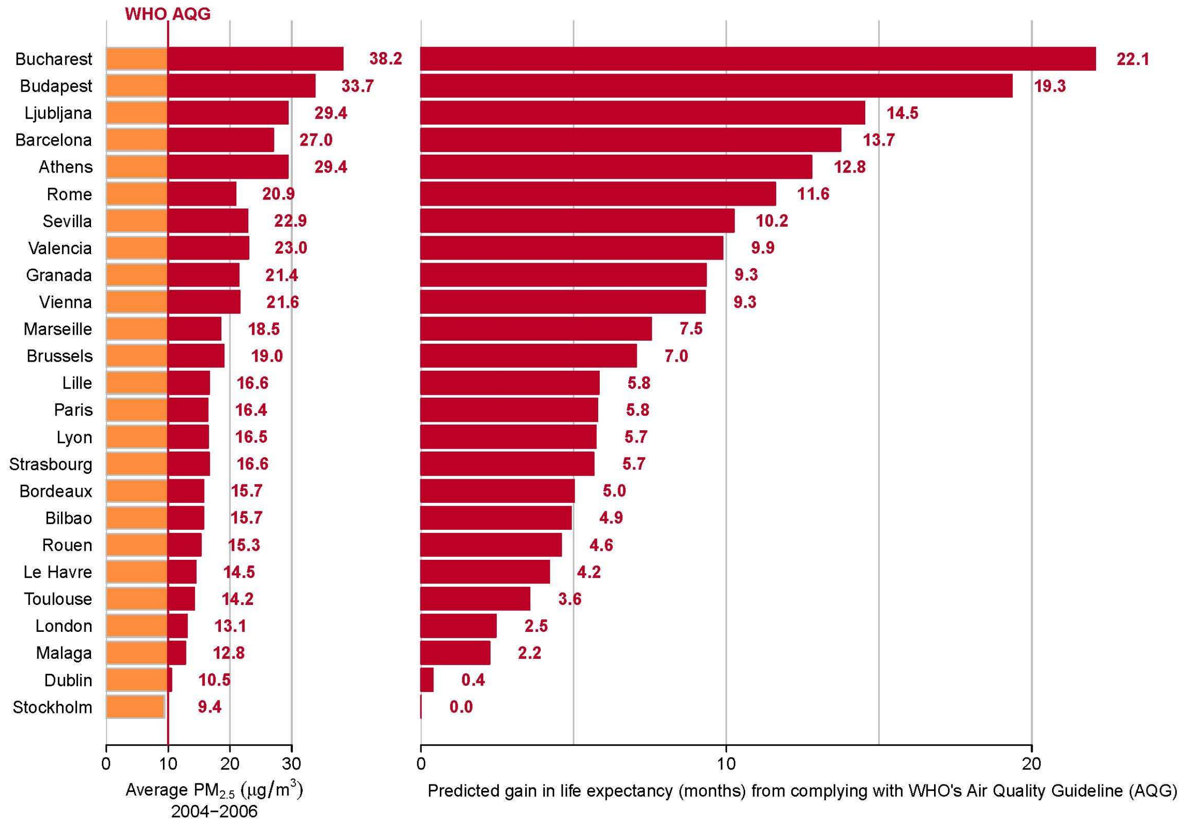
In addition, for the population studied Aphekom estimated an economic burden of more than €300 million every year attributable to chronic diseases caused by living near heavy traffic. This burden is to be added to some €10 million attributable to exacerbations of these diseases.

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. Overview of findings and local recommendations

The overall work of Aphekom for all the cities involved 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.

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 $PM_{2.5}$ to 10 µg/m^3 (WHO's Air Quality Guideline)



The results for the study indicate that Rome is among the European cities with the largest health impact (together with other Mediterranean cities like Barcelona and Valencia). The results are not surprising given the already available epidemiological literature indicated above.

A recent survey on the policies to reduce air pollution in the Italian cities (17) has been conducted. It has been shown that, even if there is an environmental improvement in the emissions standards of the vehicular fleet, number of cars per inhabitants is higher in Italy than the European mean and a general increase in the number of vehicles has been observed, mainly of diesel-fueled vehicles. Some "good practices" are reported: from vehicular transport restrictions to improvements in public transport; from the promotion of pedestrian and bicycle mobility to new forms of vehicles' use and/or ownership (car-sharing, car-pooling). Overall, however, currently available transportation policies are not in favor of sustainable mobility, both due to the elevated number of vehicles per inhabitants and to different barriers encountered in the implementation of the policies, such as the lack of an integrated approach in addressing mobility issues, the inaccurate and confusing rules in the application of the intervention and the lack of efficient control measures. As a result, the beneficial effects of local transportation regulations on urban air quality is still very limited. A national plan for air pollution is lacking.

Rome shares with other Italian cities the traffic problem together with air pollution from heating systems. The Air Quality act of the Lazio region (2010) has already indicated several policy measures that should be implemented for a long term reduction of air pollution in the city. Such a plan is based on a sophisticated modelling approach to forecast future situations. Among the positive efforts, one good example is the policy that has been implemented during the 2001-2003 to limit the overall circulation in the inner area (Traffic Limited Zone) and to limit the circulation of highly polluting vehicles within the internal railway ring. Such policies have been fruitful (18) to reduce population exposure and health effects and should be updated. In the meantime, the general emissions are decreasing and lower levels of air pollutants are being recorded along roads with high traffic (19). Such a trends are worth to be evaluated continuously.

Among the environmental problems, climate change is certainly a relevant issue and combined effects of air pollution and increased temperature have been noted (20). It is clear then that potential policy measures should address air pollution as a present menace as well as a future challenge.

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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 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]	(1)
	Respiratory hospitalizations	All	1.0114 [1.0062-1.0167]	(2)
	Cardiac hospitalizations	All	1.006 [1.003-1.009]	(2)
Short-term impacts of O_3	Non-external mortality	All	1.0031 [1.0017-1.0052]	(3)
	Respiratory hospitalizations	15-64	1.001 [0.991-1.012]	(1)
	Respiratory hospitalizations	>=65	1.005 [0.998-1.012]	(1)
Long-term impacts of PM2.5	Non-external mortality	>30	1.06 [1.02-1.11]	(4)
	Cardiovascular mortality	>30	1.12 [1.08-1.15]	(5)

PM10

For PM10, we first considered a scenario where the annual mean of PM_{10} is decreased by 5 µg/m^3, and then a scenario where the same PM_{10} annual mean is decreased to 20 µg/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, $\Delta x = 5\ \mu g/m^3$
- 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 $\mu g/m^3$. 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 $\mu g/m^3$.

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

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 $\mu g/m^3$. $\Delta x = 5\ \mu g/m^3$

PM2.5

For PM2.5, we first considered a scenario where the PM2.5 annual mean is decreased by 5 $\mu g/m^3$, and then a scenario where the PM2.5 annual mean is decreased to 10 $\mu g/m^3$ (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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