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

Local city report

Bilbao

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Summary

APHEKOM project has 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 in the Metropolitan area of Bilbao (population 706533) during the period 2004-2006. Average concentrations for PM10 and PM2.5 were 36 and 16 µg/m^3 respectively.

Short- term impact. A decrease of 5 µg/m^3 in annual average PM_{10} concentration, which represents a 14% decrease in relation to current levels, would postpone 17 deaths/year (2.5/100000 inhabitants), 81 respiratory hospitalizations/year and 20 cardiac hospitalizations/year. Furthermore, complying with WHO guidelines would postpone 56 deaths/year (7.9/100000 inhabitants), 260 respiratory hospitalizations/year and 63 cardiac hospitalizations/year.

Long-term impact. A decrease of 5 µg/m^3 in annual average $PM_{2.5}$ concentration, would postpone 172 deaths/year (34.1/100000 inhabitants), 104 due to cardiovascular causes. A gain of 4.3 months in life expectancy at 30 would be derived. Complying with WHO guidelines would rend slightly higher benefits: it would postpone 195 deaths/year (38.6/100000 inhabitants), 104 due to cardiovascular causes, and a gain in life expectancy of almost 5 months.

The economic annual benefits derived from a better air quality down to WHO guidelines in Bilbao area would be €6 millions in the short term and more than €7 hundred millions in the long term. A better quality in exposure indicators has pictured a more precise evaluation of the derived health benefits, which would be of considerable importance.

Furthermore, the additional long-term impact on the development of chronic diseases from living near busy roads has been assessed in the city of Bilbao (population 351.179) for year 2006. In Bilbao 14% of asthma cases (age 0-17), 23% of chronic obstructive pulmonary diseases (age ≥65) and 31% of coronary heart diseases (age ≥65) are attributable to living near busy streets (within 150 m of a road that bear more than 10 000 vehicles/day).

Acronyms

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

APHEIS. Monitoring the effects of air pollution on health in Europe

ENHIS. Environment and Health Information System

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

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.

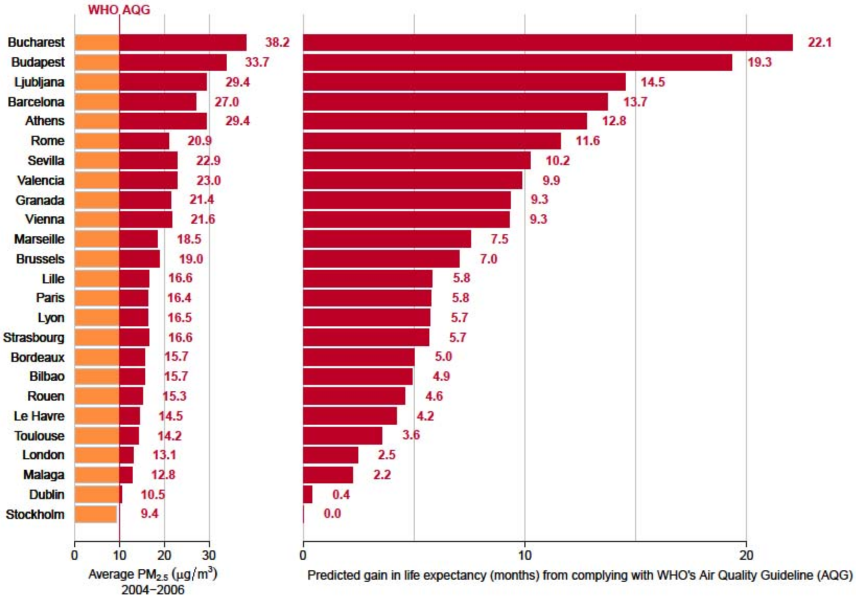
The Health Department of Basque Government has participated in the European projects with data from Bilbao Metropolitan area. Results from a previous HIA conducted in Bilbao in 2004 for APHEIS project rendered that 2002 PM_{10} annual mean was 32.2 µg/m^3; both short and long term effects of PM_{10} were assessed. As short term effects are concerned, in 2002 daily PM_{10} levels above 20 µg/m^3 would have triggered 127 respiratory and cardiac hospital admissions, and brought forward 62 deaths. Long term effects were an order of magnitude larger. If annual mean of PM_{10} were reduced to 20 µg/m^3, 584 deaths/year would be delayed and, approximately, 2700 years of life saved, what would imply an increase in lifetime expectancy of 0.9 years at the age of 30.

A further HIA within ENHIS project found that as short term effects of O3 were concerned, each reduction of 10 µg/m^3 in maximum daily 8-hour moving average concentrations would delay 9 deaths/year in the study area, 4 from cardiovascular diseases, and 3 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 PM2.5 on mortality and life expectancy in populations 30 years of age and older.

For APHEKOM project, availability of better pollution indicators in Bilbao Metropolitan area have allowed for a more precise HIA for the period 2004-2006 .

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/m3 (WHO's Air Quality Guideline)



1.1. Description of the study area

The Greater Bilbao has approximately 890 000 inhabitants and it is made up of Bilbao and neighbouring municipalities at both banks of the Nervion River. The stu dyarea is defined to represent the estimated average exposure of the population; the municipalities were selected because they make up one urban area, affected by the same pollution and meteorological phenomena, and they are Bilbao, Barakaldo, Getxo, Erandio, Leioa, Portugalete, Santurtzi and Sestao. The total area is 118,6 Km^2; Bilbao is the biggest town with 41,3 Km^2 . (Figure 1).

Figure 1 – Map of the study area

Climatology

The climate is oceanic, with high rainfalls and mild winters; sea-land and land-sea local breeze are the predominant winds. In 2009 the mean temperature was 14.9 ºC, the mean of minimum temperature was 10.2 ºC and the mean of maximum temperature was 19.9 ºC; total annual precipitation was 1136.86 mm.

Population in the study area

The study area sums up a population of 706533. Population over 65 years is 142288 (20,1%).. The population density of the study area is 5998,3 inhabitants/Km^2; the most heavily populated is Portugalete with 15349,38 inhabitants/Km^2, whereas Erandio is the least populated (1314 inhabitants/Km^2).

1.2. Sources of air pollution and exposure data

Sources

Although, in the past, industry was the most important source of air pollution in the Metropolitan Area of Bilbao, with very high levels of SO_2, since the 90s traffic has become a very important source.

Exposure data

In the Metropolitan Area of Bilbao the pollution indicators are measured by an automatic network managed by the Environment Department of the Basque Government.

APHEKOM guidelines ("Data request for health impact assessment of air pollution en the Aphekom cities, 2010") were followed and monitoring stations were selected for the period 2004-2006 if more than 75% of hourly values were available; monitors that did not overlap the interquartile range of the other monitors were excluded. All of them are representative of the area, situated in residential settings and they are not directly influenced by local sources of air pollution and showed very good correlation coefficients.

A total of 7 monitors for PM_{10} and 4 for $PM_{2.5}$ were used (β absorption method). PM_{10} data were corrected for the standard method using the factors available for each monitoring station (Environment Department). For ozone a selection of 9 monitoring stations with UV absorption method was used. The 8 hour moving averages of each day have been calculated and selected the maximum, to create the series of 8 hr daily maximum moving average.

PM_{10} levels are very similar to those in 2002 and above WHO guidelines. Graphs 3 and 4 show great variability among daily concentrations and many days with very high levels; 20 % of days PM_{10} was higher than 50 µg/m^3 (daily maximum level according to Directive 2008/50), similarly to 2002 data.

Smaller particles PM2.5 data were not available in 2002 but a conversion from PM_{10} was used; average concentration in 2004-2006, 16 µg/m^3 , is higher than WHO guidelines which is 10 µg/m^3.

Graph 2 shows the seasonal pattern of ozone. In Bilbao Metropolitan area average concentrations comply with European Directive and WHO guidelines.

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 8h max)	61	21	21	94
***PM_{10}* (daily average)**	36	17	15	70
$PM_{2.5}$ (daily average)	16	9	5	33

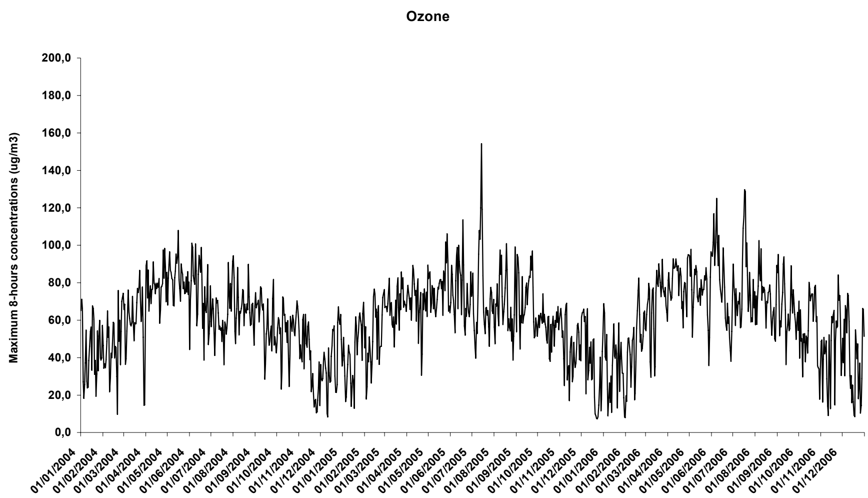


Figure 2 – Ozone concentration in the study area

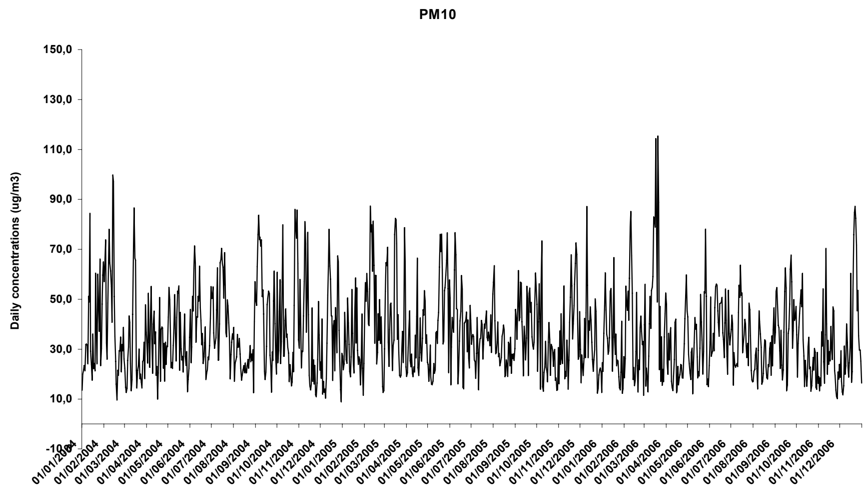


Figure 3 – *PM_{10}* concentration in the study area

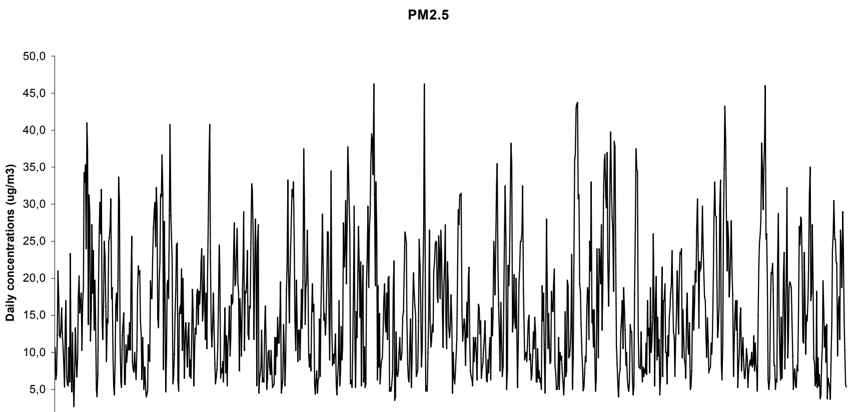


Figure 4 – $PM_{2.5}$ concentration in the study area

1.3. Health data

We used mortality data of 2004-2006, provided by the Mortality Register of the Basque Autonomous Community. The register used ICD10 and has a quality control programme; its completeness is 100%.

Hospital admissions data of years 2004 to 2006 came from the Hospital Discharge Register of the Basque Autonomous Community and they were coded using ICD9. A Quality control programme is run; the completeness of the Register is 99.9% and the percentage of missing data in cause admission was 0.3%.

Table 2 – 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	5840	827
Non-external mortality	< 800	A00-R99	> 30	5793	1147
Cardiovascular mortality	390-429	I00-I52	> 30	1883	373
Cardiac hospitalizations	390-429	I00-I52	All	6541	926
Respiratory hospitalizations	460-519	J00-J99	All	14387	2036
Respiratory hospitalizations	460-519	J00-J99	15-64 yrs	2592	367
Respiratory hospitalizations	460-519	J00-J99	≥ 65 yrs	4685	663

*** 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. The HIA method is detailed in Annex 1.

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.

1.4.1. Short-term impacts of PM_{10}

For PM_{10}, we first considered a scenario where the annual mean of PM10 is decreased by 5 µg/m^3, and then a scenario where the PM10 annual mean is decreased to 20 µg/m^3, the WHO annual air quality guideline (WHO-AQG).

A decrease of 5 µg/m^3 in annual average PM_{10} concentration, which represents a 14% decrease in relation to current levels, would postpone 17 deaths/year (2.5/100000 inhabitants), 81 respiratory hospitalizations/year and 20 cardiac hospitalizations/year. Furthermore, complying with WHO guidelines would postpone 56 deaths/year (7.9/100000 inhabitants), 260 respiratory hospitalizations/year and 63 cardiac hospitalizations/year; benefits from the latter scenario are thrice the former.

Table 3 — Potential benefits of reducing annual PM_{10} 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/m³	17	2.5
Decrease to 20 µg/m³	56	7.9

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

Table 4 — Potential benefits of reducing annual PM_{10} 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/m³	47,8	6,8	20	2.8
Decrease to 20 µg/m³	153,2	21,7	63	8.9

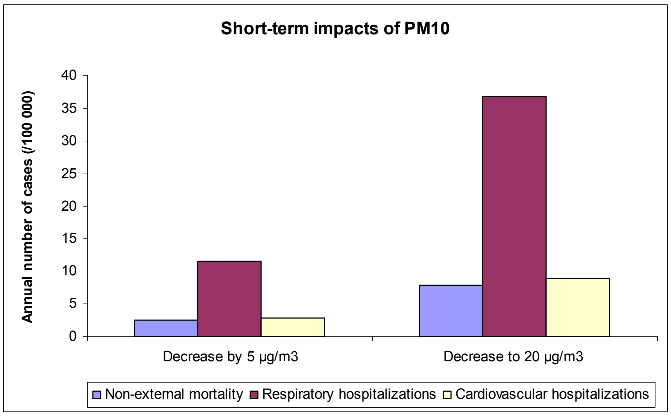


Figure 5 — Potential benefits of reducing annual PM_{10} levels on mortality and on hospitalisations

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/m³. 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/m³.

We first considered a scenario where all daily values above 160 µg/m³ were reduced to WHO-IT (160 µg/m³), then a scenario where all daily values above 100 µg/m³ were reduced to WHO-AQG (100 µg/m³), and lastly a scenario where the daily mean is decreased by 5 µg/m³.

As our city complies with WHO references no benefits could be derived from the first scenarios. A decrease of 5 µg/m³ in annual average O3· concentration, would postpone 9 deaths/year (1.3/100000 inhabitants), and 1.3 and 11.7 respiratory hospitalizations/year from those of 15-64 and over 64 years old respectively.

Table 5 ─ 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	0.5	0.1
Decrease by 5 µg/m^3	9.0	1.3

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

Table 6 ─ Potential benefits of reducing daily ozone levels on hospitalizations

Scenarios	Respiratory hospitalizations (15-64)		Respiratory hospitalizations (>64)	
	Total annual Nº of cases potsponed	Annual Nº of cases potsponed per 100 000	Total annual Nº of cases potsponed	Annual Nº of cases potsponed per 100000
8h max daily values >160 µg/m^3 = 160 µg/m^3	0	0	0	0
8h max daily values >100 µg/m^3 = 100 µg/m^3	0.1	0	0.6	1.4
Decrease by 5 µg/m^3	1.3	0.3	11.7	8.2

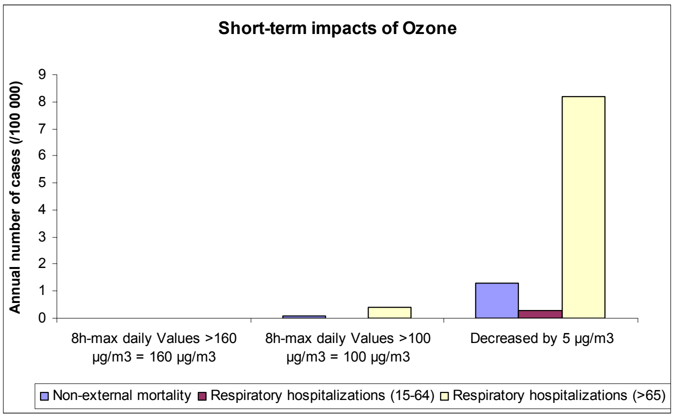


Figure 6 ─ Potential benefits of reducing daily ozone levels on mortality and on hospitalisations

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

For PM2.5, we first considered a scenario where the PM2.5 annual mean is decreased by 5 µg/m^3, and then a scenario where the PM2.5 annual mean is decreased to 10 µg/m^3 (WHO AQG).

A decrease of 5 µg/m^3 in annual average PM2.5 concentration, would postpone 172 deaths/year (34.1/100000 inhabitants), 104 due to cardiovascular causes. A gain of 4.3 months in life expectancy at 30 would be derived. Complying with WHO guidelines would produce slightly higher benefits: it would postpone 195 deaths/year (38.6/100000 inhabitants), 104 due to cardiovascular causes and a gain in life expectancy of almost 5 months.

Table 7 – Potential benefits of reducing annual $PM_{2.5}$ levels on total mortality and on life expectancy

Scenarios	Total annual Nº of deaths postponed	Annual Nº of deaths postponed per 100000	Gain in life expectancy (years)
Decrease by 5 µg/m^3	172	34.1	0.36
Decrease to 10 µg/m^3	195	38.6	0.41

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

Scenarios	Total annual number of deaths postponed	Annual number of deaths postponed per 100 000
Decrease by 5 µg/m^3	104	21
Decrease to 10 µg/m^3	117	23

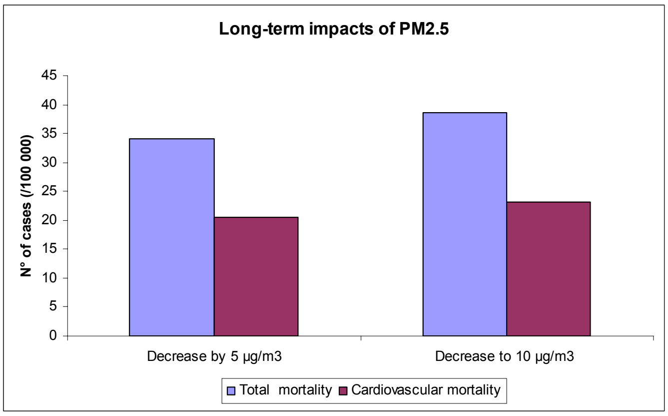


Figure 7 – Potential benefits of reducing annual $PM_{2.5}$ levels on mortality

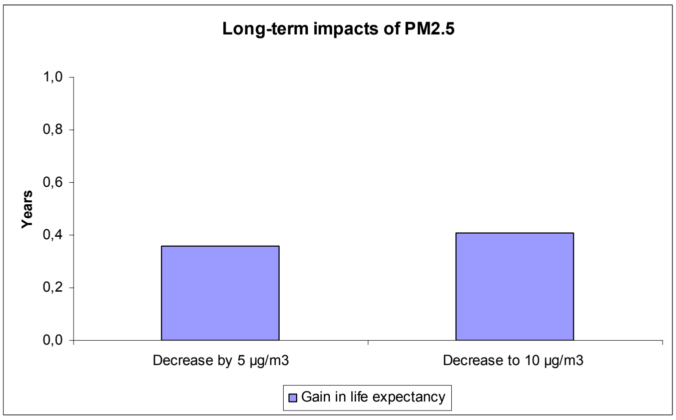


Figure 8 – Potential benefits of reducing annual $PM_{2.5}$ levels on life expectancy

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 depend on the short- or long-term nature of the exposure to air pollution (see Appendix 2). The gain in life expectancy estimated is detailed in Appendix 2.

NOTE: the valuation of mortality benefits is based on stated preferences studies and will use common values for all cities together. Indeed, accounting for differences in country's GNP per capita seems ethically unacceptable to stand for the valuation of life benefits.

Hospitalisations

The standard cost of illness approach is used for short-term hospitalisations, and consists in applying unit economic values to each case, including direct and indirect costs.

Spain average lengths of stay and costs have being used for Bilbao area economic valuation (see Appendix 2). The economic benefits related to a reduction in air pollution exposure are then computed by multiplying the number of hospitalisations by the corresponding unit economic value.

Table 9 .Economic benefits of lowering suspended particles (PM 10 short term and PM2.5 long term effects) in €

	Short term effects		Long term effects	
	Deaths	**Hospitalizations**	**Deaths**	**Life expectancy**
Decrease by 5 μg/m^3	1,5E+06	2,2E+05	2,8E+08	3,6E+08
Decrease to 20 μg/m^3	4,9E+06	7,5E+06	3,2E+08	4,1E+08

1.4.5. Interpretation of findings

The number of deaths that would be postponed in the short term if Bilbao levels of PM_{10} were lowered to WHO guidelines, 56 per year, is similar to the results obtained in our previous HIA as exposure levels are comparable and concentration –response function (CRF) has been the same.

Most robust available CRFs for respiratory and cardiovascular hospitalizations have rendered higher number hospitalizations avoided per year in Bilbao, up to three times for respiratory hospitalizations.

Ozone levels are lower in urban areas, like our study area, than in the periphery of the city and in some parts of the countryside, places where urban citizens may actually go to on a regular basis, particularly in summer. A consequence of this is that the use of urban average ozone levels may underestimate the actual exposure.

The benefits of lowering air suspended particles measured as $PM_{2.5}$ below the WHO guideline, 10 μg/m^3, would represent that 195 deaths/ year would be postponed and the life expectancy at 30 would increase 5 months. The fact that in 2004 HIA within APHEIS the gain in life expectancy was twice as high come from the uncertainties in exposure estimation as $PM_{2.5}$ monitoring stations were not available in 2002. A better quality in exposure indicators has pictured a more precise evaluation of the derived health benefits, which are in any case of considerable importance.

The short and long term economic annual benefits derived from a higher air quality down to WHO guidelines in Bilbao area would be €6 millions in the short term and more than €7 hundred millions .

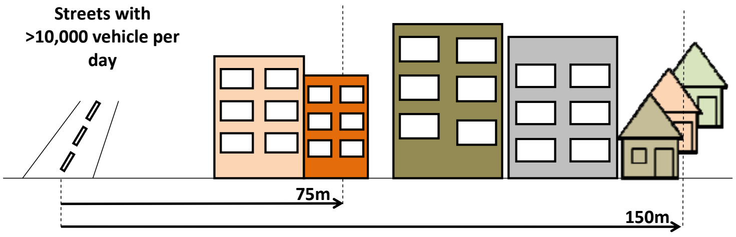
Some of the uncertainties of previous HIA have been solved, as seen in the exposure estimation or some CRFs. Furthermore the high quality of our registries of mortality and hospitalizations makes that baseline data for estimation of attributable cases are very reliable.

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.

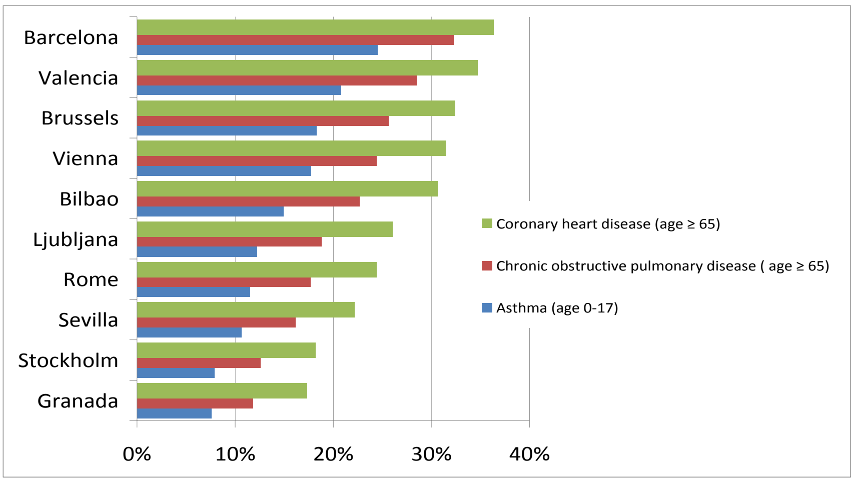


Figure 10 – Percentage of population with chronic diseases whose disease is attributable to living near busy streets and roads in 10 Aphekom cities

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.

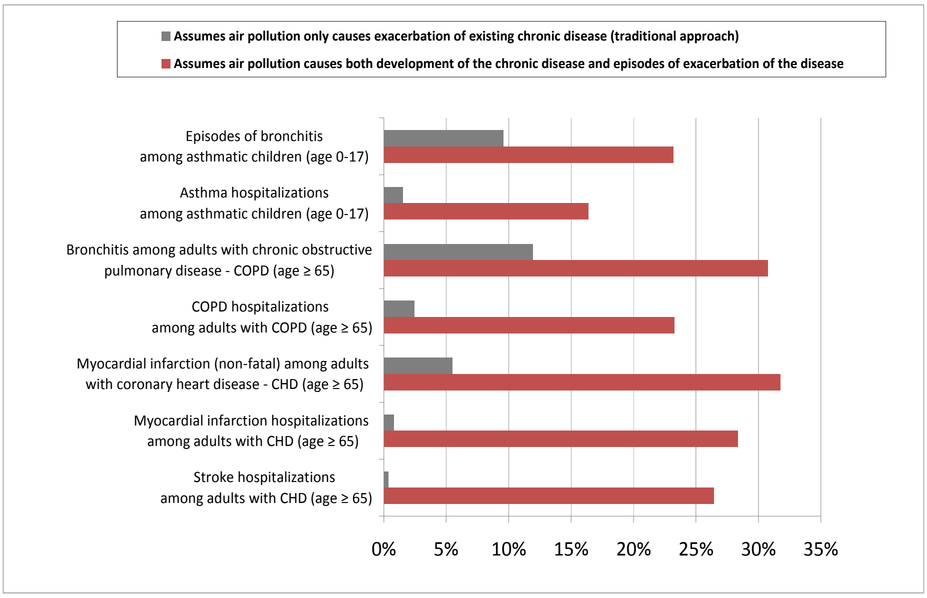


Figure 11 – Comparison of impact of air pollution on chronic diseases calculated using two different HIA approaches in Aphekom

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. Overview of findings and local recommendations

A better estimation of the exposure assessment to air pollutants has allowed a more reliable assessment of the benefits derived of lowering suspended particles in Bilbao area. Complying with WHO guidelines for PM_{10} and $PM_{2.5}$ would save, at least, more than 320 hospitalizations and would delay around 200 deaths per year; that would mean an increase in life expectancy of almost 5 months.

Current levels of PM_{10} seem not have changed in the whole area for the last years; however average PM_{10} in 2008 in the city of Bilbao is 20% lower than in the whole area. Although traffic through nearby motorways and heavy roads has not diminished, Bilbao city centre yes has suffered a transformation during the last years when many streets have become pedestrian and the suburban network has extended. However 29% and 59% of Bilbao city population lives yet within 75 m or 150m respectively of roads which bear more than 10 000 vehicles/day. Although local baseline prevalence of evaluated chronic diseases evaluated were not available, the health impact assessment of this smaller scale air pollution can not been neglected; local strategies for limiting traffic in the city centres will have quantifiable health and economic benefits

In any case, smaller reduction in average suspended particles, as 5 µg/m^3 of PM_{10} would bring measurable and not negligible benefits.

Acknowledgements

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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 9 – 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 PM2.5	Total mortality	>30	1.06 [1.02-1.11]	(7)
	Cardiovascular mortality	>30	1.12 [1.08-1.15]	(8)

PM_{10}
For PM10, we first considered a scenario where the annual mean of PM10 is decreased by 5 µg/m^3, and then a scenario where the same PM10 annual mean is decreased to 20 µg/m^3, the WHO air quality guideline (WHO-AQG).
The exposure indicator of PM10 was the annual mean, calculated as the arithmetic mean of the daily concentrations of the selected stations. The corresponding Δx for the two scenarios are:

- Scenario 1, $\Delta x = 5\ \mu g/m^3$
- Scenario 2, $\Delta x = ([PM10]_{mean} - 20\ \mu g/m^3)$.
  $\Delta x = 0$ if $[PM10]_{mean} < 20$

Ozone

For ozone, WHO set two values for the daily maximum 8-hours mean. The interim target value (WHO-IT1) is set at 160 $\mu g/m^3$. 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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