The public health benefits of reducing air pollution in the Barcelona metropolitan area

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List of acronyms

$\mu g/m^3$	micrograms per cubic meter
95%CI	95% Confidence Interval
BS	Black Smoke
CAFE-CBA	Clean Air For Europe cost-benefit analysis
CB	Chronic bronchitis
COI	Cost of Illness
CRF	Concentration-Response Function
ECRHS	European Community Respiratory Health Survey
EU	European Union
EPA	Environmental Protection Agency
HIA	Health Impact Assessments
LE	Life Expectancy
LY	Life years
NO_2	Nitrogen Dioxide
PM	Particulate Matter
PM_{10}	Particulate Matter with diameter inferior to 10 micrometers
$PM_{2.5}$	Particulate Matter with diameter inferior to 2.5 micrometers
QALY	Quality Adjusted Life Years
TSP	Total Suspended Particles
US	United States
VOLY	Value of Life Years
VSL	Value of Statistical Life
WHO	World Health Organization
WTP	Willingness-To-Pay

Executive Summary

In the last decade, numerous studies conducted in animal and human populations have confirmed that exposure to current levels of ambient anthropogenic air pollution lead to a wide range of adverse health effects, including disease and death. More recent research suggests that pollutants emitted by cars and trucks are of particular health concern. A few studies even show that morbidity and mortality promptly decreased in areas where air quality improved.

Despite open research questions, the amount of information has become large enough to approximately quantify the burden of health problems that can be attributed to ambient air pollution in a given region, country, or city. Such risk assessment – or the translation of research findings into a quantifiable public health burden - is an important tool to inform policy makers and the public about the size of the current problem and, thus, about the potential public health benefits of air pollution regulations.

Air quality measurements in recent years revealed high levels of pollution in many urban areas of the world. Research shows that current levels of air pollution in Barcelona and adjacent municipalities is particularly high and constitutes a health hazard. For example, inhalable particulate matter (PM_{10}), tiny particles of solid or liquid origin suspended in the air with a diameter of up to 10 micrometres (µm), and the gas nitrogen dioxide (NO_2) – a marker of traffic related pollution - regularly exceed current standards set by the World Health Organization (WHO) to protect health.

Strategies are being prepared by the Generalitat de Catalunya to improve air quality in those areas of Catalonia with the highest concentrations of pollution. The first step is the implementation of a mitigation plan for the Barcelona metropolitan area. The short-term goal of this plan is to reduce air pollution to comply by 2010 with the current standards legislated in the European Union (EU).The objective of this study was to estimate the health benefit that is expected to result from a reduction of air pollution in the Barcelona metropolitan area.

Methods

The method used to estimate the health benefits is based on standard approaches to derive the number of adverse effects that are attributable to some established risk factor. These methods are needed as it is not possible to directly observe or count the number of health problems due to risk factors such as smoking, diet, or air pollution. The calculation requires three basic pieces of information, namely 1) the current total frequency or occurrence of a health problem in the population, 2) the current level of pollution and the expected future level to derive the *change* in the concentrations that people are exposed to, and 3) the quantitative information about the association between exposure to air pollution and the occurrence of health outcomes.

Selected health problems: This study focused on the evaluation of three main types of health outcomes relevant for individuals and health authorities in terms of severity and burden that they represent: all-cause mortality, including deaths due to acute and long-term exposure to air pollution, morbidity, including chronic bronchitis and asthma related symptoms, and health care use represented by hospital admissions for cardiovascular and respiratory diseases.

Selected pollution: While air pollution consists of a complex mixture of hundreds of toxic constituents, risk assessments cannot be conducted for each substance one by one. The most useful approach is to use a marker of urban air pollution, and most risk assessments use ambient particulate matter (PM) to describe the burden of pollution and the benefits of regulations. This project is also based on PM, namely on PM_{10}. Benefits were obtained comparing levels of PM_{10} to which the population is currently exposed to the expected levels after reduction of pollution. The current average population exposure to PM_{10} was estimated to be approximately 50 µg/m^3 for 57 contiguous municipalities around the municipality of Barcelona and totaling a population of nearly 4 millions inhabitants.

Scenario of interest: Research existing worldwide suggests that adverse effects of ambient pollution occur already at very low levels with no evidence for a threshold below which no effects exist. As a consequence, any improvement of air quality leads to health benefits, and – vice versa – a further deterioration of air quality in the Barcelona area will further increase the current health burden attributable to pollution. Thus, quantification of benefits was done by comparing the current burden with the one expected if air quality was at some lower levels.

This project chose two lower levels to quantify the health impact of air pollution. One set of calculations estimate the health benefit of the air pollution mitigation plan of the Generalitat de Catalunya to achieve the current EU air quality standards. Thus, this scenario quantifies the benefit of the current PM_{10} population mean exposure concentration being decreased by approximately 10 µg/m^3 to meet the current EU PM_{10} standard of 40µg/m^3 annual mean. As shown in many regions and countries, sustained mitigation plans result in sustained air quality improvements. Thus, a second set of calculations was developed to quantify the annual health benefit assuming pollution is further decreased to comply with the annual mean level proposed by the World Health Organization (WHO) to protect the health of people. This second scenario quantifies the benefit of the current PM_{10} population mean exposure concentration being decreased by approximately 30 µg/m^3 to meet with the recommended WHO standard of 20 µg/m^3 annual mean for PM_{10}.

Monetary value of the benefits: Given that societies have limited resources to allocate to projects and policies, a transformation of health benefits into monetary values is often welcomed by policy makers and the public. These costs may then be directly compared to costs of mitigation investments. Based on such evaluations, the United States Environmental Protection Agency concluded few years ago that one of the most efficient regulations they ever proposed was the one targeting air quality. The total investments to improve air quality were estimated to be far smaller than the benefit for the society. However, there are ongoing discussions and debates about the most appropriate methods to derive costs of morbidity and mortality, with some methods used more often in air pollution cost-benefit assessments than others, but with no definitive agreement reached on the subject yet. This study provides the range of costs (Euro's per year) using one approach commonly used in the past, and a more recent approach proposed by European projects, and discusses limitations around these estimates.

Benefits

Health benefits of complying with the PM_{10} standard proposed by WHO

The study found that reducing current levels of air pollution to the WHO standards would result in about 3,500 fewer annual deaths (about 12% of all deaths among people 30 years and older), estimate that includes 520 deaths due to short-term exposure to air pollution. This decrease in mortality risk would represent about 14 months increased in life expectancy. In addition to the reduction in death rates, it was estimated that this reduction in air pollution could result per year in a total of 1,800 fewer hospitalizations for cardio-respiratory diseases, a total of 5,100 fewer cases of chronic bronchitis symptoms among adults, a total of 31,100 fewer cases of acute bronchitis among children, and a total 54,000 fewer asthma attacks every year among children and adults.

Health benefits of complying with the current EU air quality standard

Meeting with EU regulated levels by 2010 is a first step in a long-term strategy required to meet the more stringent WHO standards. The study found that reducing current levels of air pollution to the EU standards would already result in substantial health benefits, reaching approximately a third of those listed for the WHO scenario. For example, under this scenario, the annual death toll in the Barcelona metropolitan area could be lowered, on average, by approximately 1,200 deaths per year (about 4% of all natural deaths among people 30 years and older), representing a five months increase of the life expectancy. This reduction in air pollution could also result in a total of 600 fewer hospitalizations for cardio-respiratory diseases per year, a total of 1,900 fewer cases of chronic bronchitis symptoms among adults, a total of 12,100 fewer cases of acute bronchitis among children, and a total 18,700 fewer asthma attacks every year among children and adults.

Monetary benefits

The monetary valuation shows that the health benefits for the WHO scenario could translate approximately to an average cost of 700 Euros per person per year based on a revised method proposed by the Clean Air For Europe (CAFE) program, and 1,600 Euros based on the approach most commonly used so far in these types of evaluations, or an average total of 3,000 and 6,400 million Euros per year, respectively. For the scenario assuming a reduction of PM_{10} to EU regulated levels, the study found that the health burden listed above could translate to average costs of 300 Euros per person per year for the CAFE approach and 600 Euros per person per year for the "common" approach, or an average total of 1,100 and 2,300 million Euros per year, respectively. Estimates obtained by the two methods present uncertainty ranges around the central values that largely overlap.

Discussion and conclusions

Evidence of the role of air pollution in causing adverse health effects and death is very strong with hundreds of epidemiological studies conducted all over the world including many studies in Barcelona. This CREAL risk assessment study also demonstrates the strong impact of air pollution on public health, in line with other estimations in Europe.

In contrast to events such as deaths due to traffic accidents, the air pollution impact cannot be directly counted and the quantification of this impact could only be roughly approximated. In fact, the assumptions and approach used for this estimation are likely to have underestimated the total benefits that could actually be obtained by reducing air pollution. The most important neglected burden are the following:

- The list of health effects associated with air pollution is far larger than those presented in the risk assessment. The study did not separately assess effects of pollution on myocardial infarction, arrhythmia, and stroke as they may be included to a large extent – but not completely - in the hospitalization and mortality estimates. The study did not include less severe adverse health effects known to be caused by air pollution, such has eye irritation, cough and other respiratory symptoms, nor consequences of ailments such as increased self-medication, and school or work absences, as there are no population based data detailed enough to quantify this burden in Barcelona.

- The study did not quantify the total burden of air pollution but only the benefit of a reduction from current levels of PM_{10} to 40 µg/m^3 and 20 µg/m^3, respectively. As there is no evidence of the existence of a threshold below which no health effects may occur, further reductions below 20 µg/m^3 PM_{10} are expected to lead to additional health benefits.
- The study only used PM_{10} to quantify the problem, while pollution is far more complex. Some other pollutants may have independent effects – such as ozone – or may interact with PM and thus enhance the effects of PM. Availability of pollution data and/or respective epidemiological studies is not sufficient to use in this local risk assessment. Other studies, e.g. in the United Kingdom or the United States, have included pollutants such as ozone demonstrating additional burden.
- Barcelona has an extremely high traffic density coupled with one of the highest population densities in Europe. In other words, many people live, work, and spend their time very close to street traffic. More recent research suggests a detrimental role of those pollutants that occur in very high concentrations within the first 50-100 meters along streets. Traffic proximity distributions are currently not available for Barcelona, thus, this new evidence could not be used in this risk assessment. The health burden due to traffic is, however, expected to be clearly underestimated by this assessment. Also, a few studies measuring PM directly on persons while they walk, bike, and drive in a city similar to Barcelona lead to the conclusion that personal exposure to PM_{10} is even higher for many people than what is measured at the monitors, while those form the basis of the estimated concentrations used.

The results obtained in this study are *estimates* that come with uncertainties intrinsic to this type of evaluation. The uncertainty range presented in this study includes the one observed in the quantitative association between PM_{10} and health and, when considering all outcomes, averages approximately 50% around the estimates. Although not as large and more difficult to quantify, due to lack of information, other data used in the calculations come with inherent uncertainties, such as the distribution of PM_{10} concentrations across the region or the frequency of health outcomes (e.g. symptoms) which are estimates based on surveys.

This study shows that decreasing PM_{10} levels in the Barcelona metropolitan area would lead to substantial health benefits. Some strategies to abate pollution lead to very immediate and sustained improvements in air quality, but the question remains whether health benefits will be immediate as well. A recent intervention study showed immediate and sustained reductions in mortality rates following the ban of coal use in the city of Dublin. Similarly, symptoms in children have been shown to improve if air pollution declines. However, it is reasonable to expect that not all benefits of improved air quality will be detectable in the first year. In general, acute effects of pollution (e.g. hospitalizations) are expected to be reduced in parallel to the improvements of air quality, but a reduction of chronic effects (e.g. decrease in the rates of new cases of lung cancer, asthma, or chronic obstructive pulmonary diseases) of air pollution may take longer to materialize. Based on theoretical models conducted elsewhere, it has been estimated that one could expect 40% of the total annual death benefits to materialize in the first year.

As further elaborated in the discussion, the concept of 'attributable death', while a useful approximation in the short term of a couple of years, is not appropriate to express the long-term benefits of pollution reduction simply by multiplying the results of this study by the number of future years. This is due to the fact that death is ultimately not 'preventable' but can only be postponed through prevention of morbidities. Thus, change of the life expectancy and the estimation of years of life lost due to pollution are more appropriate to quantify the long-term benefits of interventions. This is especially relevant to estimate long-term monetary benefits of air pollution reduction strategies.

In summary, the study shows that improvement of air quality in the Barcelona metropolitan area to comply with current EU standards or with the more stringent standards recently proposed by WHO is expected to have substantial immediate as well as long-term health benefits for the people living in Barcelona area.

1. Introduction

1.1 Air pollution and health

Experimental studies conducted in cellular systems, animals, as well as humans and a large number of epidemiological studies have shown that the current levels of ambient anthropogenic air pollution lead to morbidity and mortality in humans [1]. The acute effects of air pollution, i.e. effects that occur within hours or days of exposure, are particularly well investigated with several studies conducted in Spain [2, 3]. Depending on the frailty and susceptibility of subjects, the acute effects of current levels of ambient pollution range from minor annoyance, reduction of pulmonary function, or mild respiratory symptoms to more severe respiratory as well as cardiovascular effects such as the exacerbations of asthma attacks or chronic bronchitis, or the triggering of arrythmias, myocardial infarction and strokes. Due to these more severe effects it has been shown that doctors visits, emergency room visits and hospital admissions all increase on days with higher pollution. The most severe effects of air pollution relate to death. Mortality rates gradually increase as air quality deteriorates. Because these effects occur not only during severe air pollution episodes but at all levels of pollution, there is no evidence for 'safe levels' of air pollution. The every-day long-term exposure to air pollution also contributes to chronic pathophysiologic changes and chronic diseases which ultimately lead to reduced life expectancy. Several cohort studies, both from the United States (US) and Europe confirm that current levels of air pollution reduce life expectancy and effects are particularly strong for cardiovascular mortality and lung cancer [4]. An increasing number of studies also suggest that people living very close to busy streets experience additional adverse health effects, including asthma, and death [5, 6].

Open questions remain and are subject to intense international research. These include investigations of the mechanisms that cause the observed health effects and the characterization of the toxicologically most relevant constituents and sources. However, numerous experimental studies already confirm a role of several pathophysiologic pathways that ultimately cause the observed effects [7]. Thus, evidence for a causal adverse role of air pollution has substantially increased in the past years and the use of evidentiary data in risk assessments has become increasingly prevalent.

1.2 Air pollution in Barcelona and surrounding areas

Air quality, namely particulate matter (PM) and nitrogen dioxide (NO_2), in Barcelona and surrounding areas is poor. Trends in the recent years show a degradation of the situation [8]. The concentrations of these pollutants largely exceed standards developed to protect public health and adopted in other regions such as the US, the State of California, and several European countries. Pollution levels also regularly exceed the air quality guidelines recommended by the World Health Organization (WHO) to protect public health [9]. For example, in the city of Barcelona, in 2004, the annual mean concentration of particulate matter with a diameter below 10 µm (PM_{10}) was 49 µg/m^3 (average of six existing fixed monitors), 45 µg/m^3 in 2005, and 50 µg/m^3 in 2006, when the recommended WHO annual mean air quality guideline is 20 µg/m^3. The annual mean at each of the six monitors exceeded this value as well. To put this in context, **Table 1.1** presents the annual mean PM_{10} for Barcelona compared to levels in other cities around the world as provided in the WHO air quality guideline report [9].

Several epidemiological studies have shown evidence of the adverse effects of air pollution on the population of Barcelona. For example, short-term exposure to high levels of air pollution increased the risk of mortality in populations with preexisting chronic diseases [10]. The very high traffic density coupled with an unusually high density of inhabitants and street canyons suggests that the health impact of air pollution and specifically traffic related pollution may be a particularly serious problem in the area.

There is currently a large effort conducted by regulatory authorities in Barcelona and surroundings to reduce air pollution. A first step in this effort is the development of a mitigation plan to reduce air quality levels to standards legislated in the European Union (EU), specifically directive 1999/30/CE that regulates limit values for NO_2 and PM_{10} in ambient air that are regularly exceeded. The annual mean limits for NO_2 and PM_{10} are currently set to 40 µg/m^3. While this limit is far less stringent than the standards recommended by the scientific community and the recently published air quality guidelines of WHO to protect public health, reduction to these levels is a very important first step for all those European cities with severe problems of air quality. Under the EU directive, member states shall take the measures necessary to ensure that NO_2 limit value of 40 µg/m^3 (annual mean) is not exceeded by 2010. The limit values for PM_{10} of 40 µg/m^3 (annual mean) should have been met since the 1st of January 2005. In October 2006, the Council of the EU agreed on a new draft directive on ambient air quality and cleaner air for Europe that has been sent to the European Parliament for second lecture. The new draft maintains a mean annual limit value of 40 µg/m^3 for PM_{10} with a maximum of 35 daily exceedances per year of 50 µg/m^3. The draft also introduces $PM_{2.5}$, particles with diameter inferior to 2.5 micrometers, in the legislation with a mean annual limit of 25 µg/m^3 to be met in 2015 with a reduction of 20% $PM_{2.5}$ annual levels from the means 2008-2010 to 2018-2020. The new WHO guidelines recommend a $PM_{2.5}$ annual mean of 10 µg/m^3, while the US National Air Quality Standards is set at 15 µg/m^3 and the California standard to 12 µg/m^3. In 2005, all the new draft limit and target values were exceeded in Barcelona. For example $PM_{2.5}$ daily levels ranged from 25 to 35 µg/m^3 at three locations (L'Hospitalet, Sagrera, Diagonal avenue) from 1999-2006. [11-13]. $PM_{2.5}$ is not yet regularly monitored in the Barcelona metropolitan area.

Table 1.1. Annual average PM_{10} concentrations observed in selected cities worldwide

Continent	**City**	**Annual average PM_{10} concentrations** (µg/m^3)
Asia	New Delhi	160
	Seoul	60
	Tokyo	30
Latin America	Lima	110
	Mexico City	55
	Sao Paulo	49
Africa	Cairo	150
	Cape town	25
Europe	Prague	60
	Barcelona	55
	Roma	55
	Oslo	45
	London	25
	Stockholm	20
North America	San Diego	50
	Los Angeles	48
	New York city	25

Source: *[9] WHO. Air quality guidelines. Global update 2005.*

1.3 Evaluating the public health impact of air pollution

Scientists and public health agencies have increasingly engaged in the assessment of the public health impact of ambient air pollution. Such assessments consist of the translation of research findings into a rough quantification of the total health problem in a given region, country, or city that may be attributable to air pollution. They can also serve as a rough quantification of the likely benefits to public health of policies to reduce air pollution. Such translational work is very effective to inform the policy makers and the public about the approximate size of the problem. Although individual effects of air pollution are in general rather small –i.e. smaller than the effects of active smoking– the public health impact of air pollution can be rather substantial. The reason for this paradox stems from the fact that the whole population is exposed to air pollution, at least to some degree, whereas only a minority of the population are active smokers. Moreover, air pollution is often high in the most densely populated areas, thus the overall health burden is further increased.

The methods of the air pollution impact assessment have been developed during the last 15 years [14]. The methods have been discussed in WHO committees leading to recommendations by experts. Governmental agencies in the United Kingdom and other European countries as well the US and Californian Environmental Protection Agency (EPA) employ these methods regularly, and a committee of the US National Academy of Science approved the general approaches. Health Impact Assessments (HIA) for air pollution have been applied to various geographic scales ranging from rough global assessments to more sophisticated international, national or local studies.

Several HIAs have recently been conducted in Europe for which different estimates of the burden of air pollution were provided for Spain and/or for the city of Barcelona. All of these studies show that the overall health burden attributable to air pollution arises principally from effects on mortality in adults of long-term exposure to particulate matter.

One of the first HIA conducted in Europe was the "trinational study" [15]. This study estimated the impact of outdoor and traffic-related air pollution on public health in Austria, France, and Switzerland. The study found that air pollution caused 6% of total mortality or more than 40,000 attributable cases per year. About half of all mortality caused by air pollution was attributed to motorized traffic, accounting also for: more than 25000 new cases of chronic bronchitis (adults), more than 290,000 episodes of bronchitis (children), more than 0.5 million asthma attacks, and more than 16 million person-days of restricted activities.

Another HIA is the Air Pollution and Health: A European Information System (APHEIS) [16-18]. APHEIS was created in 1999 to provide policy and decision makers, environmental and health professionals, the general public and the media with resources on air pollution. The city of Barcelona is one of the city from the APHEIS network. The last evaluation of APHEIS, APHEIS-3, estimated that 11,000 premature deaths in Europe could be prevented annually if long-term exposure to $PM_{2.5}$ was reduced to 20 μg/m^3. The evaluation was based on a total population of almost 39 million inhabitants. Also it estimated that on average, life expectancy of a 30-year-old person could be prolonged, depending on the geographic area, by 2 to 13 months if $PM_{2.5}$ concentrations did not exceed 15 μg/m^3.

a third HIA is the European Network of Health Information System (ENHIS) [19]. ENHIS is a methodological package dealing with the feasibility of HIAs for different environmental risk factors. For outdoor air pollution, the HIA aims to derive the number of health events that could be prevented from air pollution (PM_{10} and ozone) in different target populations (children, adults, elderly and general population) for different cities in Europe. For Barcelona, results were centered on death and hospital admissions due to ozone for the general population and infant mortality due to PM_{10}. In Barcelona, the HIA showed that each reduction by 10 µg/m^3 of the daily 8-hour moving average concentrations of ozone would prevent 22 deaths per year in the general population, 11 from cardiovascular diseases, and 9 from respiratory causes. In terms of hospital admissions, this decrease would represent avoiding one respiratory admission in the adult population (15 to 64 years) and 21 in the population over 64 years. All other things being equal, the reduction of the annual average levels of PM_{10} to 20 µg/m^3 would prevent 0.45 total post neonatal deaths. Reducing PM_{10} daily mean values to 20 µg/m^3 would prevent 10 hospital respiratory admissions among children 15 or less. The relatively small numbers of prevented cases obtained in this evaluation is due to low ozone levels in Barcelona as well as very low infant mortality.

A fourth HIA is the Clean Air for Europe Cost-Benefit Analysis (CAFE-CBA) [20]. The aim of CAFE-CBA was to develop a long-term, strategic and integrated policy advice to protect against significant negative effects of air pollution on human health and the environment. CAFE-CBA estimated the health burden of outdoor air pollution based on level of emissions projected to 2020 for all of Europe and by member states with respect to different legislation policies. This HIA also provides a cost-benefit analysis for change in emissions in Europe. CAFE-CBA estimated that based on year 2000 levels and compared with current legislation, air pollution caused about 22,000 premature deaths in Spain as well as other morbidity diseases, which could represent per capita a total cost between 400 euros to 1,000 euros per year, depending on the method of calculation selected.

Following its Global Burden of Disease project, the WHO has recently provided environmental burden of disease estimates by country for selected risk factors including outdoor air pollution [21]. For Spain, the burden due to air pollution was estimated to 5,800 deaths per year. This estimate assumed a reduction of the levels of PM_{10} from a mean urban level of 30 µg/m^3 to 20 µg/m^3, the recent recommended WHO limit value for PM_{10}. This estimate only took into account cities greater than 100,000 inhabitants, which represented in this estimate 42% of a total population of 43.1 millions.

Although the health burden of air pollution in Spain and Barcelona has been roughly estimated through these European studies, a detailed assessment has yet to be conducted.

2. Objectives

This project conducts a health impact assessment (HIA) of air pollution for the Barcelona metropolitan area.

The main objective of this study is to provide a first estimate of the potential health benefit that would result from a stepwise improvement of the air quality for the residents of this area. This study also presents an estimate of the translation of some of these benefits into monetary values.

The results of the study are expected to provide useful information to policy makers and the public.

3. Methods

3.1 General framework

The general methodological framework of air pollution HIA has been described in several reports and papers [14, 15, 22, 23]. It consists in the application of methods used for decades to derive the risk attributable to specific risk factors such as smoking. The attributable fraction is the fraction of a health problem that can be attributed to a specific exposure (compared to a baseline exposure) or to a change in exposure. If the total occurrence of a health problem is known in a specific target population, attributable cases can then be derived for this population. Under the assumption that none of the attributable cases would occur in the absence of exposure, the attributable fraction is often referred to as the "preventable burden".

The main information required to estimate attributable cases consists of three quantities, (1) the frequency of a health problem in the population, in other words the number of events per year for that specific health problem (2) the level of exposure to the risk factor in the population, and (3) the quantitative association between exposure and the health outcome (the concentration-response function or CRF).

In addition to these quantities, the assessment of the health burden of air pollution depends on the definition of the study area, the choice of exposure metrics, the selection of health outcomes included in the assessment, and the selection of "reference levels".

The following paragraphs detail the specific data and methodology used in this evaluation in relation to these central issues.

3.2 Study area

The city of Barcelona is located on the central coast of Catalonia in the Northeast of Spain but is part of a larger urban and industrial area extending several kilometers to the north, west and south of the city. This extended area is commonly referred to as the Barcelona metropolitan area. However, the precise geographic extension of the Barcelona metropolitan area is not clearly established and varies depending on local entities that refer to it. For this project, a continuous geographic area constituted by 57 municipalities was selected as the area of study. This area was selected for its geographical continuity and expected similarity in terms of air pollution exposure. This area will be referred as the Barcelona metropolitan area throughout the text, and refers to a wider definition than defined by other entities. The municipality level reflects the smallest unit for which data was available.

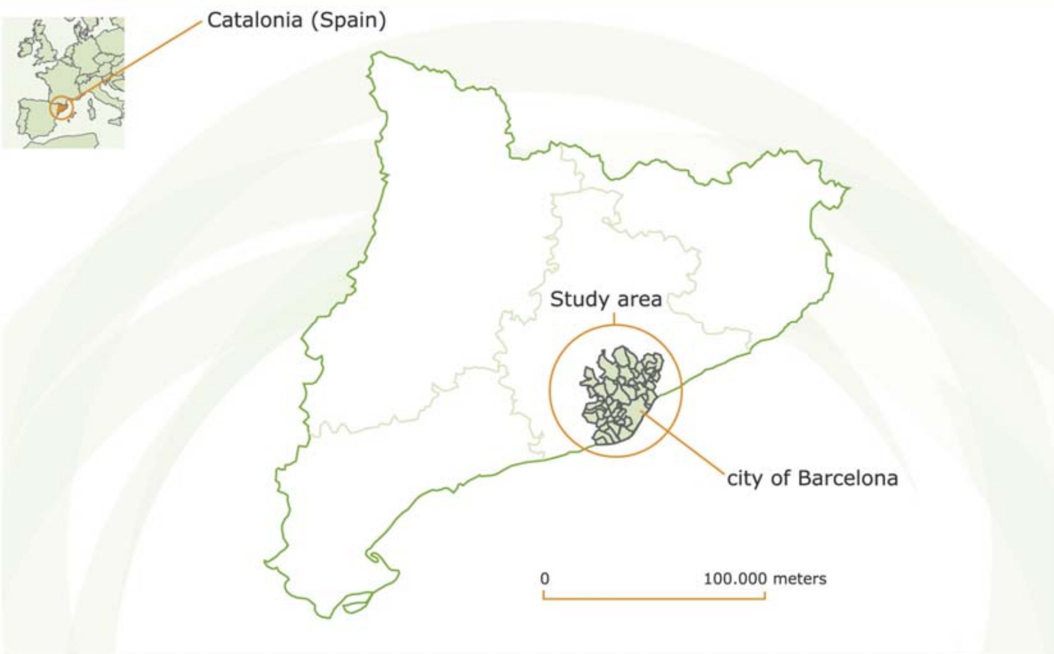
Figure 3.1 present the study area in relation to its regional geographic location. **Table 3.1** presents the distribution of the population for the 57 municipalities included in the area of study.

Table 3.1. Population distribution in the 57 municipalities of the study area, year 2004

Municipality	Zip code	Total population	% of total population	Population density (hab/km^2)
Abrera	80018	9,422	0.24	471
Badalona	80155	214,874	5.55	9,767
Badia del Vallès	89045	14,313	0.37	14,313
Barberà del Vallès	82520	27,202	0.70	3,400
Barcelona	80193	1,578,546	40.80	15,785
Canovelles	80410	14,001	0.36	2,000
Castellar del Vallès	80517	19,475	0.50	433
Castellbisbal	80543	10,352	0.27	334
Castelldefels	80569	53,964	1.39	4,497
Cerdenyola del Vallès	82665	56,065	1.45	1,809
Cervelló	80689	6,980	0.18	233
Corbera de Llobregat	80728	11,278	0.29	627
Cornellà de Llobregat	80734	83,327	2.15	11,904
El Papiol	81580	3,628	0.09	403
El Prat de Llobregat	81691	63,148	1.63	2,037
Esplugues de Llobregat	80771	45,915	1.19	9,183
Gavà	80898	43,242	1.12	1,395
Granollers	80961	56,456	1.46	3,764
Hospitalet de Llobregat	81017	250,536	6.48	20,878
La Llagosta	81056	12,944	0.33	4,315
Lliçà d'Amunt	81075	12,009	0.31	546
Lliçà de Vall	81081	5,696	0.15	518
Martorell	81141	25,010	0.65	1,924
Martorelles	81154	4,912	0.13	1,228
Molins de Rei	81234	22,496	0.58	1,406
Mollet del Vallès	81249	50,691	1.31	4,608
Montcada i Reixac	81252	30,953	0.80	1,346
Montmeló	81350	8,724	0.23	2,181
Montornès del Vallès	81363	14,065	0.36	1,407
Olesa de Montserrat	81477	20,294	0.52	1,194
Palau Solità i Plegamans	81568	12,499	0.32	833
Palma de Cervelló	89058	2,881	0.07	524
Parets del Vallès	81593	15,912	0.41	1,768
Pallejà	81574	9,746	0.25	1,218
Polinyà	81672	5,855	0.15	651
Ripollet	81803	33,605	0.87	8,401
Rubí	81846	66,425	1.72	2,076
Sabadell	81878	193,338	5.00	5,371
Sant Adrià de Besos	81944	32,921	0.85	8,230
Sant Cugat del Vallès	82055	65,061	1.68	1,355
Sant Fost de Campsentelles	82093	7,039	0.18	541
Sant Quirze del Vallès	82384	15,729	0.41	605
Sant Viçenç dels Horts	82634	26,477	0.68	2,942
Santa Coloma de Cervelló	82444	6,652	0.17	832
Santa Coloma de Gramanet	82457	116,503	3.01	16,643
Santa Perpètua de Mogoda	82606	20,844	0.54	1,303
Sentmenat	82671	6,628	0.17	237
Sant Andreu de la Barca	81960	23,675	0.61	3,946
Sant Boi de Llobregat	82009	80,636	2.08	3,665
Sant Climent	82042	3,366	0.09	306
Sant Feliu de Llobregat	82114	41,954	1.08	3,496
Sant Joan Despí	82172	30,242	0.78	5,040
Sant Just Desvern	82212	14,910	0.39	1,864
Terrassa	82798	189.212	4.89	2,703
Torrelles de Llobregat	82896	4.324	0.11	309
Vallirana	82956	11,678	0.30	487
Viladecans	83015	60,033	1.55	3,002
TOTAL AREA	**--**	**3,868,663**	**100**	**3,548[1]**

Source: *Institut d'Estadística de Catalunya, year 2004; 1. average population density.*

Figure 3.1.



Geographical location in Catalonia (Spain) of the 57 municipalities included in the study area and referred to as the Barcelona metropolitan area throughout the text.

3.3 Population exposure

3.3.1 Marker of air pollution used in this project

Air pollution is a complex mixture of often highly correlated constituents and pollutants. Epidemiological studies cannot disentangle the specific contribution of each component to health problems, and toxicological studies do not provide clear quantitative information about the dose-response of all pollutants and their interactions. Thus, health impact assessments of air pollution rely on epidemiological studies, using markers of air quality. It is not appropriate to separately assess the risk for several correlated pollutants and sum them up, as the total burden would be largely overestimated. It is widely recognized that adverse health effects of air pollution are associated with particulate matter (PM) especially. This study used PM_{10} as marker of air pollution because most studies reporting effects and used in this evaluation were based on PM_{10} exposure. although one study quantified the risk using the finer fraction of PM, namely $PM_{2.5}$, and another used Total Suspended Particles (TSP), usually corresponding to particles up to a diameter of 30 or more micrometers. In the absence of complete epidemiological data for each and every size fraction of PM it is usually required to convert across the different size fractions. This project used - where needed - a conversion factor of 0.6, i.e. assuming that $PM_{2.5}$ would reflect 60% of PM_{10} as used in previous studies [15]. This factor is similar to the ratio observed at monitoring stations in Barcelona [11-13].

There is strong evidence suggesting that ozone causes additional established health effects that are most likely independent from or synergistic with other pollutants, especially in summer. However, because the effects of ozone are acute and rather small at the prevailing concentrations of this urban area, the contribution of ozone to the total burden of urban air pollution is expected to be relatively non significant compared to the effect of PM_{10} and thus was not included in this evaluation. Effects of ozone on health for the city of Barcelona can be found in the Barcelona local city report of ENHIS HIA [19]. Results show that a decrease of the daily maximum 8-hour moving average concentrations of ozone of 10 µg/m^3 would prevent about 20 deaths (95%CI: 10-40), and about 20 hospital admissions for cardiovascular and respiratory diseases, per year. In this report, 24-hours ozone concentrations in Barcelona ranged most frequently during summer between 30 and 50 µg/m^3. The 8-hour mean WHO 2006 guideline value for protecting human health is set to 100 µg/m^3.

We emphasize that the use of a single marker of urban air pollution most likely leads to an underestimation of benefits of air management plans because these plans may reduce concentrations of several pollutants including NO_2, NO_x, benzene and others with partly independent or synergistic effects on health.

3.3.2. Determination of population exposure

To derive attributable cases for a specific change in concentration it is necessary to determine the level of exposure of the population before change occurs. In this context, by "exposure" we mean background concentrations of PM_{10} representative of people's residence. We consider the current levels as the point of reference for future changes. Several approaches are available to determine population exposures depending on the level of detail of the data available. The crudest approach consists of the use of the annual mean value(s) as measured at one monitor (selected as being 'representative' of a study area). A more sophisticated approach consists of the use of modeled pollution surfaces, overlaid to the population distributions, to derive the detailed estimates of the population exposure distributions. Depending on the availability of the data, some studies use intermediate methods.

In this evaluation, the population exposure was represented by an average concentration that took into account the population of each municipality (population-weighted average concentrations). Average concentrations were obtained for specific age-groups. The baseline year for the assessment of ambient concentrations was 2004, thus consistent with the year for which air quality data and health outcome data were available. The age groups matched those used in the guidelines studies that provide the concentration-response relationships chosen in the evaluation (see section 3.4) and include all ages, 0-1 year, 0-15 years, ≥15 years, ≥25 years, and ≥30 years.

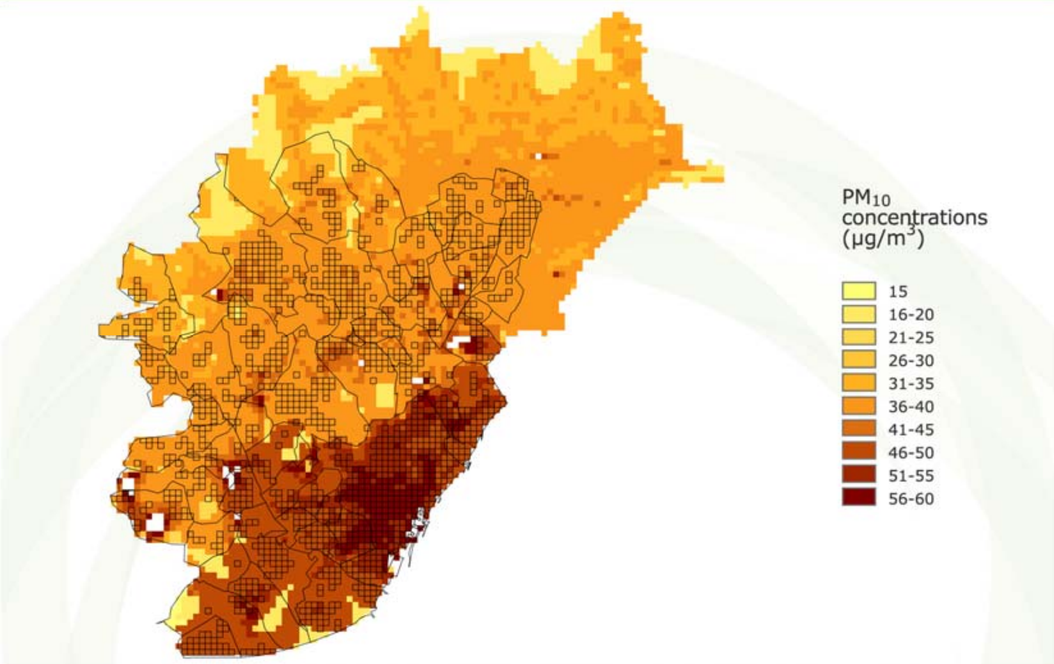
The PM_{10} average population-weighted concentrations were derived as follows. First, an average concentration for the urbanized areas within each municipality was calculated. The concentrations were extracted from a modeled PM_{10} surface concentration map developed by the Catalonia department for the environment (Departament de Medi Ambient i Habitatge de la Generalitat de Catalunya) [24]. This map was developed by applying different air dispersion models to predict concentrations in the study area for different sources of PM_{10} emissions for 2004. The surface map was validated with monitoring site locations. The concentration surface map was constituted of a grid of 500mx500m (total 6095 cells). In total we discarded 31 cells in the grid that presented concentrations at least twice as high as concentrations in neighboring cells. Those concentrations were ignored in the derivation of the population-weighted mean ambient concentration, thus people living in these cells are assumed to be exposed to the population mean level. The risk assessment is based on the total population, including these 31 cells. The concentration of cells located within an urbanized area of each municipality was averaged to obtain a mean concentration for each municipality. The map of urbanized areas was also developed by the Catalonia department of environment (Departament de Medi Ambient i Habitatge de la Generalitat de Catalunya) [8]. Grid-cells of the urbanized map that fell within two or more municipalities were split. Finally, the age-specific population-weighted average was obtained by multiplying the age-specific population of each municipality by the municipality mean concentration divided by the total age-specific population of the study area.

Table 3.2 shows the population weighted average used as representative exposure concentration for the area under study. **Figure 3.2** presents the superposition of the concentration surface map on the urbanized areas. **Graphic 3.1** presents the average PM_{10} concentration for each municipality prior to weighting. It is important to note that surface maps are the current basis for the evaluation of clean air policies in the Barcelona area, supporting their use in this assessment.

Table 3.2. Population weighted exposure concentration used in HIA. Presented for specific and partly overlapping age ranges that match the age groups used for the different health outcomes (see section 3.4)

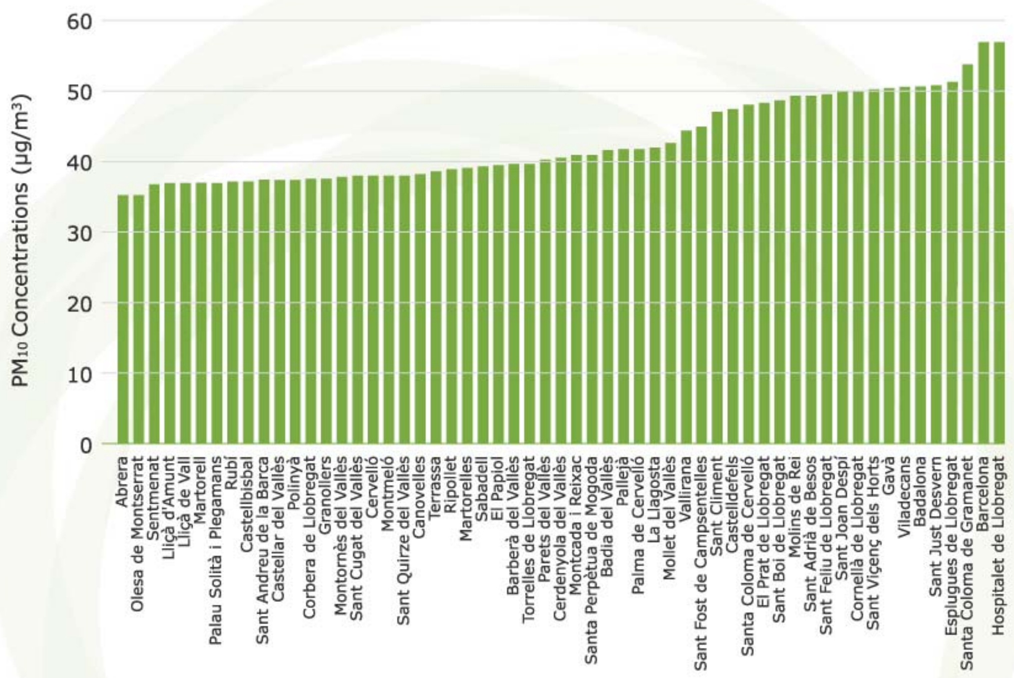
Age	**Population** (2004)	**% of total population**	**PM_{10} exposure concentration µg/m^3** (population weighted average)
0-1	38,630	0.999	49.0
0-15	520,850	13.5	49.2
≥15	3,347,813	86.5	50.3
≥25	2,897,272	74.9	50.4
≥30	2,532,824	65.4	50.4
ALL	**3,868,663**	**100**	**50.1**

Figure 3.2.



Modeled surface of the concentration of PM_{10} in the Barcelona metropolitan area for year 2004 [24]. Squares represent urbanized areas. The 57 municipalities contours are superposed to the surface map.

Graphic 3.1.



Average PM_{10} concentrations in urbanized areas of the 57 municipalities included in the study area

3.4 Health outcomes

3.4.1 Selection of outcomes

Although the impact assessment attempts to reflect the total burden of air pollution on health, the assessment was restricted to those effects with the strongest or 'best accepted' evidence for a causal role of air pollution and for which there is availability of input data, such as existence of concentration-response function (CRF) and of prevalence or incidence data of the outcome among the target population. Moreover, the assessment is restricted to health outcomes that have been used in previous risk assessments in Europe and the US.

For this evaluation, three main families of health outcomes were evaluated to represent the burden on health of air pollution in the Barcelona metropolitan area. These outcomes are mortality, morbidity including chronic diseases and asthma related symptoms, and health care use.

The impact of air pollution on mortality is a combination of acute and cumulative effects [25]. For example, air pollution of a specific day may trigger myocardial infarction, stroke or deaths within the next few days or weeks (acute or sub-acute effects due to a short-term exposure). On the other hand, air pollution may support chronic disease processes leading to morbidities that contribute to the shortening of life. Studies investigating the effects on mortality of air pollution over long periods of time have shown that these cumulative effects are larger than those assigned to acute effects [26, 27]. This assessment provides estimates for both the acute effects on mortality due to short-term exposure and the chronic effects due to long-term exposure. We assume the long-term effects to reflect the total burden including the cumulated effects of acute insults. Thus, the estimates for the acute effects will be expressed as a portion of the total. The outcome of infant mortality (<1 year) has been treated separately.

Effects of air pollution on morbidity include a range of symptoms related to effects on the cardiovascular and the respiratory systems. Morbidity effects of air pollution were evaluated for bronchitis symptoms. Short-term effects were evaluated for urgent hospitalization due to respiratory or cardiovascular diseases. In addition, air pollution has been shown to have a severe impact on susceptible individuals such as asthmatics. Thus, we evaluated separately the potential impact of air pollution in exacerbating asthma symptoms among children and adults with asthma.

Although epidemiological evidence of effects of air pollution exist for several additional outcomes (i.e. doctors´ visits and emergency room visits due to cardio-respiratory problems; school absences; and restricted activity days), the outcomes were not evaluated due to a lack of detailed enough baseline data for the population under consideration or because the evidence is still relatively weak for some of these outcomes.

3.4.2 Concentration-response function and baseline frequency of outcome

The concentration-response function (CRF) quantifies the association between a change in pollution concentrations and the related change in the adverse health outcomes in a population. The CRF is a key piece of information for the evaluation of expected health benefits for a reduction in air pollution.

The final CRFs used in this evaluation are either those published in one single study or the meta-analytic weighted average of estimates from different epidemiological studies. CRFs used in previous peer-reviewed European health impact assessments were preferred in order to allow comparability. Preference was also given to CRFs from populations comparable to that in the study area (i.e. European CRFs). A few alternative options of CRFs were used in the sensitivity analyses. Similarly, if baseline frequencies were not available for the Barcelona area, values for Europe were preferably selected.

The following section details the source and value of the CRF and baseline frequencies used for each selected outcome as summarized in **Table 3.3**.

Table 3.3. Baseline frequencies or number and concentration-response functions used in Health Impact Assessment for the Barcelona Metropolitan Area.

Outcome		Age	Population baseline frequency / number		PM_{10} Concentration-Response function	
			Number or percent	**Source**	**Mean** (95%CI) per 10 μg/m³	**Source[1]**
Mortality						
Infant death (ICD10 A00-R99)		<1	117	Catalonian mortality registry 2004	1.048 (1.022-1.075)	Pooled estimate reported in Lacasaña, et al 2005 [28]
Short-term effects All causes (ICD10 A00-R99)		All	29,473	Catalonian mortality registry 2004	1.006 (1.004-1.008)	Pooled estimate reported in WHO, 2004 [27]
Respiratory causes (ICD10 J00-J99)		All	3,052	Catalonian mortality registry 2004	1.013 (1.005-1.021)	Pooled estimate reported in WHO, 2004 [27]
Cardiovascular causes (ICD10 I00-I52)		All	9,489	Catalonian mortality registry 2004	1.009 (1.005-1.013)	Pooled estimate reported in WHO, 2004 [27]
Long-term effects All causes (ICD10 A00-R99)		≥30	29,187	Catalonian mortality registry 2004	1.043 (1.026-1.061)	Pooled estimate reported in Künzli et al. 2000 [15]
Morbidity						
Chronic diseases	Chronic bronchitis adults	≥25	0.71%	ASHMOG United States	1.098 (1.009-1.194)	Abbey et al. 1993 [26]
	Acute bronchitis children	<15	12.2%	SCARPOL Switzerland	1.306 (1.135-1.502)	Pooled estimate reported in Künzli et al. 2000 [15]
Asthma related symptoms	Asthma attacks adults	≥15	Asthmatics: 8.1% Average number attacks/year: 1.4	ECHRS II Barcelona	1.039 (1.019-1.059)	Pooled estimate reported in Künzli et al. 2000 [15]
	Asthma attacks children	<15	Asthmatics: 7.2% Average number attacks/year: 3	SARI Barcelona SCARPOL Switzerland	1.041 (1.020-1.051)	Pooled estimate reported in Ward&Ayres 2004 [29]
Health care use						
Hospital admission for respiratory diseases (ICD9 460-519)		All	34,593	CMBDAH Area of Barcelona 2004	1.011 (1.006-1.017)	APHEIS 3, 2005 [16]
Hospital admission for cardiovascular diseases (ICD9 390-429)		All	35,080	CMBDAH Area of Barcelona 2004	1.006 (1.003-1.009)	Le Tertre et al. 2002 [30]

Notes: *1. Refers to study in which derivation of pool estimated was undertaken. Further description of studies used to derive pool estimates is provided in the text.*

3.4.2.1 Mortality and life expectancy

Infant death

The CRF used for infant mortality was based on a joint estimate derived from studies over the possible impact of ambient air pollution on the fetus and infants (less than 1 year) published between 1994-2003 [28]. A CRF estimate of 4.8% (95%CI: 2.2, 7.5) change in infant mortality per 10 $\mu g/m^3$ change of PM_{10} has thus been used similarly as in the recent ENHIS HIA.

Short-term effects on mortality

As mentioned, the impact of air pollution on mortality is a combination of acute and cumulative effects. We present estimates for acute effects and consider them being part of the total cumulative effects described below, thus acute and long-term effects should not be summed. The CRF used for acute effects on mortality due to daily fluctuations in ambient concentrations of pollutants was derived from a quantitative meta-analysis of peer reviewed studies developed by the WHO on health effects and short-term exposure to particulate matter [27] derived from studies of 33 separate European cities and regions. Most of the estimates were taken from Air pollution and health: A European approach 2 (APHEA 2) study [31, 32] with Barcelona being one of the cities included. The meta-analysis provided estimate for total, cardiovascular and respiratory causes of deaths. For total effects, the CRF represents a 0.6% (95%CI: 0.4, 0.8) change in deaths per 10 $\mu g/m^3$ change of PM_{10}. We present estimates for all three outcomes but it should be emphasized that the cause-specific acute deaths are contained in the total.

Long-term effects on mortality (adults≥30 years)

For comparability purposes with other HIA in Europe (APHEIS-3), we selected a CRF derived from two US studies as proposed in the trinational HIA of Austria, France, and Switzerland [15]. These studies are known as the American Cancer Society (ACS) study [33] and the Harvard Six studies [34]. Both were based on cohorts that were broadly representative of the US population. The ACS study was based on $PM_{2.5}$ metric, thus the CRF had to be converted to PM_{10} using the conversion factor discussed above. The combination of the results of both studies result in a CRF of 4.3% (95%CI: 2.6, 6.1) change in death per 10 $\mu g/m^3$ change of PM_{10}.The ACS study was recently re-analyzed by an expert panel [35] and analyses were extended [36] confirming the results previously obtained. To date, five European studies have investigated long-term effects of urban air pollution on mortality [37-41]. All five studies found positive associations between mortality and long-term exposure to traffic-related air pollution and confirmed estimates obtained from the two US cohort studies. The European studies used, however, partly different metrics of exposure, and a direct use of these estimates or meta-analytic pooling with the US studies was not considered for this phase of the project.

Population frequencies

The data for total mortality were obtained from the Catalonian mortality registry of the department of health (Departament de Salut de la Generalitat de Catalunya). Data was provided for each municipality for year 2004. Deaths related to violence and accidents were excluded.

Gain in life expectancy

Many risk assessments provide estimates of attributable deaths which is a very common approach used for other exposures, in particular to express the burden due to smoking. If we assume that a policy decreases air pollution as of January

1st for a full year, it is in fact appropriate to expect that the number of death during this year to be lower by at least those numbers of death estimated to be attributable to acute effects. However, 'attributable death' may be a misleading concept in the long run, and in particular if one assumes 'attributable cases' to also reflect 'preventable cases'. Death is ultimately never preventable and if one follows a birth cohort, everybody dies no matter how clean the air is. Moreover, in the long run, the derived number of 'attributable deaths' does not remain constant year by year due to the change in the age distribution in a population in which age-specific mortality rates decrease. Such a population does, in essence, get older, thus the total number of death gradually increases in this aging population with a gradual decrease in the "attributable death". Due to these conceptual limitations of 'attributable death' it has been proposed to express the impact of risk factors on mortality more appropriately by quantifying the years of life lost [20]. The primary consequence of a reduction in death rates is in fact an increase in a populations life expectancy, and the appropriate way to quantify this benefit thus is in terms of the time lost [20]. This approach comes with some other limitations and assumptions but has clear conceptual advantages in particular to express the benefits of a change in air quality in the long term of years or decades and especially to translate these benefits into costs. A detailed description of this approach, advantages and limitations is presented and applied in Section 6 together with the monetary valuation.

Thus, if one assumes that life is shortened to some extent by air pollution, one can express the health effect benefits attributable to sustained improvement of ambient concentrations by the gain in the life expectancy of a population instead of presenting number of deaths. Life expectancy is the expected time remaining to live at a specific age. This can be derived using life tables that use the observed age structure of the population and age-specific mortality data to calculate the number of survivals and number of "premature" death in each age category in future years [42]. Life tables assume that the survival curve for a birth cohort predicts the temporal pattern of deaths in that cohort. Gains in life expectancy for a specific air pollution scenario are the difference between the life expectancy calculated using the observed age-specific mortality data (the reference level) for the population under consideration and the one calculated using age-specific mortality data modified by the CRF for a change in air pollution levels as defined in the policy scenario.

In this assessment, gains in life expectancy were calculated using life tables methods following Miller and Hurley [42].

3.4.2.2 Hospital admissions

The CRF for respiratory hospital admissions used in this evaluation was developed within the AHPEIS-3 report using data from nine European cities and developing a Poisson regression to model the association between daily counts of all-respiratory admissions on daily PM_{10} concentrations. The CRF represents a change of 1.1% (95%CI: 0.6, 1.7) in the number of respiratory hospital admissions per change of 10 $\mu g/m^3$ PM_{10}.

The exposure response function for cardiovascular hospital admissions used was developed by APHEA and examined the association between cardiac causes (ICD9 390-429) and PM_{10} daily levels in eight European cities with Poisson regression models [30]. The CRF represents a change of 0.6% (95%CI: 0.3, 0.9) per 10 $\mu g/m^3$ PM_{10}.

The number of respiratory and cardiovascular admissions was taken from the Barcelona registry for the Minimum Basic Data Set of Hospital Discharge (CMBDAH), Catalonia, Spain. This registry compiles data from all public hospital of the Barcelona metropolitan area with catchments areas covering all municipalities included in our study, suggesting good estimation of the baseline hospital admissions used. In addition, it has been estimated that registered discharges at public hospitals by CMBDAH represented coverage of 98% of all discharges.

3.4.2.3 Morbidity

Chronic bronchitis (adults ≥25 years)

In the absence of European studies on the association between long-term exposure to air pollution and morbidity, the CRF for the occurrence of cases of chronic bronchitis (CB) in adults derives from the ASHMOG study, a cohort of the Seventh-Day Adventist population (aged 25 years and more) from the US. This same CRF was used in the trinational HIA [15]. This cohort investigated the associations between long-term cumulative ambient concentrations and onset of CB [26]. This study used TSP as a metric. After conversion, the CRF represents a change of 9.8% (95%CI: 0.9, 19.4) per 10 μg/m^3 PM_{10}. Few other HIAs have evaluated this outcome. CAFE-CBA proposed two different risk estimates derived from the original ASHMOG study, one slightly inferior based on PM_{10} metric [43] that was used to determine core results. We compare estimates using this CRF in the sensitive analysis.

The estimation of the baseline frequency of new onset of CB is not straightforward. The disease is not monitored nor is it well defined in the available studies, thus prevalence and incidence may vary substantially depending on the definitions used to describe a range of overlapping phenotypes (such as, e.g. chronic bronchitis, chronic obstructive lung disease, emphysema etc.). Moreover, the frequency of these phenotypes very much depends on the smoking habits of the population as smoking is a very dominant cause of these diseases.

To be internally consistent, our main calculations apply the incidence of CB as observed and as defined in the ASHMOG study [26], i.e. the same study used to derive the CRF. New onset of CB was 0.71% per year in this ASHMOG population. The advantage of this choice is that the Seventh-Day Adventist population are usually life-time non-smokers, thus the observation of [26] best applies to non-smokers and is not affected or confounded by smoking – a very substantial contributor to CB.

However, it is biologically very plausible that pollutants affect these interrelated phenotypes to a similar degree rather then just one specific definition of CB. Thus, as a sensitivity analysis, we provided estimates for an alternative definition of CB as proposed in CAFE-CBA.

Acute bronchitis in children (< 15 years)

In the absence of local studies on the effects of long-term exposure to air pollution in children, the CRF for the occurrence of cases of acute bronchitis in children was derived from several studies as first used in the trinational HIA. The joint estimate comes from three studies [44-46] for age ranges 10-12, 8-12, and 6-15, respectively. Studies were conducted during the period 1980 to 1991. Definition of bronchitis in the three studies were, respectively, "did your child have a doctor´s diagnosed bronchitis within the last 12 months", "did your child had bronchitis during the last 12 months", and "did your child had an airway disease within the last 12 months". Thus the CRF represents a 30.6% (95%CI: 13.5, 50.2) change per 10 μg/m^3 PM_{10}.

In the absence of baseline frequency in the metropolitan area of Barcelona that match the definition of acute bronchitis among children of the CRF, we used a prevalence of 12.2% based on SCARPOL study. SCARPOL is a cross-sectional study conducted during 1992/1993 that investigated the association between long-term exposure to air pollution and respiratory health and allergy in Swiss children. SCARPOL contributed also to the derivation of the CRF [46].

Asthma attacks in adults (≥15 years)

In the absence of more recent estimates, the CRF for the occurrence of asthma attacks in adults used was derived and first presented in the trinational HIA [15]. The joint estimate was derived from three European adult panel studies [47-49]. The period of investigation varied between 1992 and 1995 and asthma attacks were defined as wheezing or shortness of breath. The CRF represents a 3.9% (95%CI: 1.9, 5.9) change per 10 µg/m^3 PM_{10}.

The number of asthmatics and the number of asthma attacks per adults were obtained from the European Community Respiratory Health Study (ECRHS) II and I respectively for Barcelona. The number of adults with asthma was estimated to be 8.1% based on the question "Have you ever had asthma" and "Has it been confirmed by a doctor". The mean number of asthma attacks per asthmatic adults was 1.4 and corresponds to the question "How many attacks of asthma have you had in the last 12 months". The frequency of asthma in adults for Barcelona appeared to be slightly lower than when considering all ECRHS sites (11.6%), as was the number of attacks per adult (3.6).

Asthma attacks in children (< 15 years)

The CRF used for asthma attacks was based on a joint estimate derived from a systematic review of the results of short-term effects of outdoor particulate air pollution in children [29]. The end-point outcome for this study was lower respiratory symptoms. The CRF represents a 4.1% (95%CI: 2.0, 5.1) change per 10 µg/m^3 PM_{10}.The pooled CRF is in the range of what other studies investigating symptom exacerbations and asthma have found elsewhere. The same CRF estimate was used in ENHIS HIA.

In the absence of data for the metropolitan area of Barcelona that match the CFR definition for the outcome, the number of asthma attacks per asthmatic child was obtained from SCARPOL study. Participants in this study were asked how many asthma attacks they had during the last 12 months. The underlying number of asthmatics was obtained from the cross-sectional Barcelona SARI study (Estudio sobre la Salud Respiratoria en la Infancia), that derived a prevalence of asthma based on 10,821 children aged between 7 and 8 years recruited from primary schools in the city of Barcelona and Sabadell. Thus the frequency of asthmatic children in Barcelona retained for this evaluation was 7.2% and the average number of asthma attack per child diagnosed with asthma by a doctor was retained as 3.

3.5. Scenario of interest

Due to the complexity of the causes of air pollution, its sustained reduction requires a range of strategies. Some of those lead to immediate improvements whereas others are long-term goals. To reflect the stepwise improvements of air quality we provide risk estimates for two scenarios. The main scenario estimates the ultimate benefits for health if air quality characterized by PM_{10} was in compliance with the air quality guidelines recommended by the WHO. WHO recommends a mean annual level for PM_{10} of 20 µg/m^3 or less to protect human health.

The second scenario estimates health benefits for the intermediate step of air pollution abatement, namely reducing current PM_{10} levels to the European Union (EU) air quality standard. The EU regulation states that PM_{10} levels should not exceed a mean annual level of 40 µg/m^3. This is the 2010 target for current policy implemented by authorities in Barcelona. In contrast to other risk assessments, we did not evaluate the total burden of air pollution, i.e. we ignored the impact of PM_{10} concentrations inferior to 20 µg/m^3. However, there is no evidence for a threshold of no effect and thus the benefits associated with reducing concentrations below 20 µg/m^3 are expected to be commensurately larger.

3.6. Measure of the health benefits

3.6.1 Attributable cases

The benefits of changes in air pollution are expressed as attributable cases. Attributable cases are derived from attributable population fractions estimated using CRFs, often corresponding to a relative risk (RR), and the number exposed in the community of interest. RR or similar measures are derived from epidemiological studies and represent the ratio between the frequency of cases in an exposed group compared to a non-exposed group adjusted for covariates to control confounding. The basic formula to derive the attributable population fraction (AF_{pop}) among the total population is the following:

$$AF_{pop} = \frac{p_p x(RR-1)}{p_p x(RR-1)+1}$$

Where p_p represents the fraction of the population exposed to the (environmental) factor under investigation, and RR the CRF for the change of exposure considered. There are, in general, two ways to select the CRFs, namely to use an estimate from research conducted in the target area – i.e. Barcelona in our case – or to derive pooled CR estimates based on a set of published CRFs. As other HIA we opted for the latter approach due to limited availability of Barcelona based CRFs.

If the whole population is exposed – typically the case in air pollution studies - p_p equals 1 and the above formula can be simplified to the following equation, equal to the attributable fraction among the exposed.

$$AF_{\exp} = \frac{RR-1}{RR}$$

¡Error! No se pueden crear objetos modificando códigos de campo. From this fraction, attributable cases are obtained by multiplying AF_{exp} by the total number of cases observed in the population. This is obtained either by direct count or by multiplying the known or assumed underlying frequency of the outcome in the population by the total population. The two alternative formulas to

$$Attributable\ cases = AF_{\exp}\ x\ I_t\ x\ N$$

or

$$Attributable\ cases = AF_{\exp}\ x\ N_c$$

derive the number of attributable cases are shown below:

Where I_t is the underlying frequency of the outcome in the population, N_c, is the number of people with the outcome in the population, and N is the total number of persons in the population under consideration.

To scale the CRF derived from published data to the exposure contrasts of interest in the HIA, RR has to be modified as follows:

$$RR = e^{Ln\left(RR_{published} / Unit_{published}\right) x\, \Delta \exp}$$

Where Δexp is the change in concentration expected for the scenario under consideration and $Unit_{published}$ is the unit for which the RR was published or derived.

Finally, the statistical models used in epidemiological studies most often provide odds ratios (OR) from logistic regression models rather than RR. For rare events or small effects, RR and OR are similar, however, for frequent events and when the OR is large, OR may overestimate the true RR. To take this into account, when appropriate, we corrected OR's using the following standard formula [50].

$$RR = \frac{OR}{1 + I_t\, x\,(OR - 1)}$$

Where I_t is the frequency of the outcome in the population.

3.6.2 Impact numbers

In addition to attributable cases, we also describe the results obtained deriving case impact numbers (CIN). These measures have been developed to help communicate the impact on the population of a change in exposure [51]. A CIN is the number of people with the disease for whom one case is attributable to the exposure and is in fact the reciprocal of the AF_{pop}. For an exposure that includes the whole population, CIN has the following formula:

$$CIN = \frac{RR}{RR - 1}$$

3.7. Expression of uncertainty

The various steps described above all come with a range of assumptions and uncertainties, which differ for the different outcomes. The burden and benefit assessment is, thus, not a precise reflection of the reality but a crude estimate of what is expected to change in public health if air quality improves, keeping all other things equal. To reflect the uncertainties in these numbers, risk assessors usually provide some boundaries around the point estimates. In addition there are uncertainties and assumptions that cannot be quantified, thus, these would not be reflected in quantitative boundaries. A further way to express uncertainties consists, therefore, in the calculation of risks adopting different assumptions, to provide insight in the sensitivity of the main results to the underlying assumptions and changes in data.

This assessment reflects a similar strategy to that used in other projects. First, all our final results are rounded to the next 10, 100, or 1,000. Second, we provide the point estimate and an upper and lower bound. Those are based only on the uncertainty in the CRF published in epidemiological studies. We arbitrarily chose the value of the 5th and 95th confidence interval of the CR function corresponding to ±1.96 times the standard error (se) of the estimates. Other risk assessments have used ±1.0 se, thus providing narrower bounds [52]. Third, we conducted a series of sensitivity analyses using alternative assumptions for the most influential or most controversial input data and assumptions, to gain insight into the overall influence of these factors.

4. Results

Table 4.1 presents the health benefits that could be obtained if PM_{10} annual mean in the Barcelona metropolitan area was reduced to 20 µg/m^3 and 40 µg/m^3, respectively. As shown, the benefits of achieving the more stringent WHO levels is approximately three fold those gained once air quality is in compliance with current EU standard. Results for each health outcome are further described below.

Table 4.1. Expected health benefits per year for a reduction of PM_{10} annual mean in the Barcelona metropolitan area expressed as prevented number of cases and percent of total cases.

Outcome		Age	Health benefits (95%CI)			
			Decrease to annual mean concentration of 20 µg/m^3		Decrease to annual mean concentration of 40 µg/m^3	
			Prevented number of cases	% of total cases	Prevented number of cases	% of total cases
Mortality						
Infant death	All	<1	15 (7-22)	13 (6-19)	5 (2-7)	4 (2-26)
Death due to short-term exposure (acute)	All causes	All	520 (350-690)	2 (1-2)	180 (120-230)	0.6 (0.4-0.8)
	Cardiovascular causes	All	250 (140-360)	3 (2-4)	90 (20-120)	0.9 (0.5-1.3)
	Respiratory causes	All	120 (50-190)	4 (2-6)	40 (20-60)	1.3 (0.5-2.1)
Total death (long-term exposure; includes above acute effect)	All	≥30	3,500 (2,200-4,800)	12 (7-16)	1,200 (760-1,700)	4 (3-6)
Hospital admissions						
	Respiratory causes	All	1,150 (630-1,670)	3 (2-5)	390 (210-570)	1.1 (0.6-2)
	Cardiovascular causes	All	620 (310-930)	2 (1-3)	210 (110-310)	0.6 (0.3-0.9)
Morbility						
Chronic diseases	Chronic bronchitis adults	≥25	5,100 (550-8500)	25 (3-41)	1,900 (190-3400)	9 (1-17)
	Acute bronchitis children	<15	31,100 (17,500-40,500)	49 (28-64)	12,100 (6,100-17,400)	19 (10-27)
Asthma related symptoms	Asthma attacks adults	≥15	41,500 (21,000-60,500)	11 (6-16)	14,700 (7,300-21,800)	4 (2-6)
	Asthma attacks children	<15	12,400 (6,400-15,200)	11 (6-14)	4,000 (2100-5,000)	4 (12-5)

4.1 Mortality

4.1.1 Attributable deaths

The estimated reduction in the number of premature deaths per year for a decrease in air pollution from current annual PM_{10} level in the Barcelona metropolitan area to an annual mean of 20 µg/m^3 is 3,500 (95%CI: 2,200-4,800). This estimation includes 520 deaths (95%CI: 350, 690) due to acute effects on mortality and 15 deaths (95%CI: 7, 22) due to infant mortality (<1 year old).

In other words, if the levels of PM_{10} in the Barcelona metropolitan area were reduced from the current levels to an average annual level of 20 µg/m^3 as recommended by WHO, the annual number of death due to natural causes in the Barcelona metropolitan area is expected to decrease by 12% (95%CI: 7%-16%), this representing one for every 8 (95%CI: 6-13) persons who die from natural causes.

The intermediate scenario of a reduction of PM_{10} concentration to 40 µg/m^3 would lead to one third of the above benefits. Namely, the annual death toll could be reduced by 1,200 (95%CI: 760-1,700) or 4% (95%CI: 3%-6%) of all cases, representing one out of 24 deaths (95%CI: 17-38) in the Barcelona metropolitan area being attributed to air pollution above the current EU standard.

4.1.2 Gains in life expectancy

As mentioned in the methods section, a more appropriate way to express the benefit of lower air pollution on death rates is, in the long run, in terms of change in life expectancy. **Table 4.2** presents a summary of gains in life expectancy expected for reductions in air pollution. If the current annual mean of PM_{10} decreased to 20 µg/m^3, as recommended by WHO, the expected gain in life expectancy of a 30-year-old person would be on average 14 months (95%CI: 9-20) due to a reduced risk of death from all causes.

Once the levels of PM_{10} in the Barcelona metropolitan area are reduced to 40 µg/m^3, the expected average gain in life expectancy of a 30-year-old person would be 5 months (95%CI: 3-7). This represents approximately one third of the benefits obtained with the WHO scenario. In 2004, the life expectancy of a 30 year old individual in Catalonia was 51.53 years with a life expectancy at birth of 80.75 years [53].

Table 4.2. Health benefits expressed as time gained for a reduction of PM_{10} annual mean in the Barcelona metropolitan area.

Outcome	Unit	Age	**Health benefits** (95%CI)	
			Decrease to annual mean concentration of 20 µg/m^3	Decrease to annual mean concentration of 40 µg/m^3
Gain in life expectancy	Months	30	14 (9-20)	5 (3-7)

4.2 Hospital admissions

If the levels of PM_{10} in the Barcelona metropolitan area were reduced from the current levels to an average annual level of 20 µg/m^3, the number of hospital admissions could be reduced by 1,150 (95%CI: 630-1,670) cases per year for respiratory causes, and by 620 (95%CI: 320-930) cases per year for cardiovascular causes. This represents 3% (95%CI: 2%-5%) of all respiratory admissions and 2% (95%CI: 1%-3%) of all cardiovascular admissions. Expressed as impact number, this means that for every 30 (95%CI: 21-55) and 56 (95%CI: 38-111) respiratory and cardiovascular hospitalization, respectively, one case could be prevented if air pollution was reduced to the WHO level.

If the levels of PM_{10} in the Barcelona metropolitan area were reduced from the current levels to an average annual level of 40 µg/m^3 as in the intermediate scenario, the number of hospital admissions would be reduced by 1% (95%CI:

0.6%-2%) for respiratory admissions and 0.6% (95%CI: 0.3%-0.9%) for cardiovascular admissions.

4.3 Morbidity

4.3.1 Chronic diseases

4.3.1.1 Chronic bronchitis in adults (≥25 years)

If the levels of PM_{10} in the Barcelona metropolitan area were reduced from the current levels to an average annual level of 20 µg/m^3, the number of adults with chronic bronchitis could be lowered per year by 5,100 (95%CI: 550-8,500) or 25% (95%CI: 3%-41%) of all cases, this representing one case for every 4 (95%CI: 2-37) adults that have chronic bronchitis in the Barcelona metropolitan area.

If the levels of PM_{10} in the Barcelona metropolitan area were reduced from the current levels to an average annual level of 40 µg/m^3 as for the intermediate scenario, the number of adults with chronic bronchitis would be reduced by 9% (95%CI: 1%-17%).

4.3.1.2 Acute bronchitis in children (<15 years)

If the levels of PM_{10} in the Barcelona metropolitan area were reduced from the current levels to an average annual level of 20 µg/m^3, the number of children with acute bronchitis could be lowered per year by 31,100 number of cases (95%CI: 17,500-40,500) or 49% (95%CI: 28%-64%) this representing one case for every 2 (95%CI: 2-4) children with acute bronchitis in the Barcelona metropolitan area.

If the levels of PM_{10} in the Barcelona metropolitan area were reduced from the current levels to an average annual level of 40 µg/m^3 as for the intermediate scenario, the number of cases of acute bronchitis in children attributable to air pollution could be reduced by 19% (95%CI: 10%-27%).

4.3.2 Asthma related symptoms

4.3.2.1 Asthma attacks in adults (≥15 years)

If the levels of PM_{10} in the Barcelona metropolitan area were reduced from the current levels to an average annual level of 20 µg/m^3, the number of asthma attacks in adults could be lowered per year by 41,500 (95%CI: 21,000-60,500) or 11% (95%CI: 6%-16%) of all asthma attacks.

If the levels of PM_{10} in the Barcelona metropolitan area were reduced from the current levels to an average annual level of 40 µg/m^3 as for the intermediate scenario, the number of asthma attacks in adults would be reduced per year by 4% (95%CI: 2%-6%).

4.3.2.2 Asthma attacks in children (<15 years)

If the levels of PM_{10} in the Barcelona metropolitan area were reduced from the current levels to an average annual level of 20 µg/m^3, the number of asthma attacks in children would be lowered by 12,400 (95%CI: 6,400-15,200) or 11% (6%-14%) of all asthma attacks observed per year.

If the levels of PM_{10} in the Barcelona metropolitan area were reduced from the current levels to an average annual level of 40 µg/m^3 as for the intermediate scenario, the number of asthma attacks would be further reduced by 4% (95%CI: 2%-5%).

5. Discussion and sensitivity analyses

5.1 General comments

This assessment shows that estimated health benefits of improved air quality in the Barcelona area are substantial. If PM_{10} levels were in compliance with the current EU standards mortality would be some 4% lower. Achieving air quality standards proposed by WHO to be enforced as a measure to protect people's health would result in three-fold larger benefits.

To better interpret these results it is important to acknowledge a range of assumptions and uncertainties that are inevitable in such risk assessments. Most importantly, these estimates should be considered as an indication of the magnitude of benefits that could be attained rather than exact numbers. As discussed below, most assumptions and, in particular, the lack of data lead to an underestimation or an incomplete assessment of the impact, thus, the public health benefits can be expected to be larger than presented in this report.

We presented total results for a specific study area. The results related to smaller geographic levels (i.e. municipality level) would leave larger uncertainties because the outcome frequencies and the exposure concentrations may be different compared to those of the aggregated study area. The surface map of PM_{10} concentrations and the population distribution show that the results are very much influenced by the coinciding high population density and concentrations of PM_{10} in the municipality of Barcelona and few other municipalities. It is for these reasons that results are not expressed by municipality.

There are a number of other uncertainties related to the development of these estimates. These uncertainties involve each of the components of the methodology such as selection of outcomes, and frequency of these outcomes, CRFs, selection of indicator(s) of pollution, and the related population exposure distribution. Below is a review of those uncertainties with **Table 5.1** summarizing expected effects on estimates of the different elements used in the HIA. Section 5.4 provides a sensitivity analysis of the degree of the impact of some of the sources of uncertainties identified with strongest effects on the estimates.

The range of estimates presented in our tables is based on the uncertainty around the CRFs. While we provide three estimates for each outcome using the statistical uncertainty of the CRFs, namely the main estimate and an upper and lower bound, it has to be emphasized that not all values within this interval are an equally likely reflection of the (unknown) true function. In general, values closer to the main estimate are more likely to be appropriate whereas the upper and lower bound reflect more extreme and less likely alternatives. However, it may also be possible that the true (unobservable) association between PM_{10} and health would be smaller or larger then the observed estimates. These latter two scenarios each have a probability of only 5%.

Our main analyses only quantified uncertainty in the CRFs. The development of more complex uncertainty distributions using probabilistic models to integrate other uncertainty requires additional data that were not available for Barcelona. Several sources of uncertainty and the sensitivity to alternative assumptions are instead discussed below.

Table 5.1. Summary of expected effects on estimates of the different elements used in the HIA.

Elements	Expected effect on estimates
Concentration-response functions	
Recent studies suggest larger CRF for mortality (long-term)	↓
Transferability from other settings	→?
Health outcomes	
Number of outcomes evaluated	↓
Role of chronic diseases in acute exacerbations	↓
Frequency of health outcomes	→?
Definition of outcomes	→↑
Population exposure	
Choice of exposure concentration to PM_{10}	→
PM_{10} as indicator of air pollution	↓

Notes:
↑: likely to have overestimated effects
→: likely to have minimal effects on estimates
↓: likely to have underestimated effects

5.2 Concentration-response function

The CRF is one of the most influential components in the calculation of the health impact. For evaluating the long-term effects on mortality, we used older US CRFs, instead of more recent US or European estimates, for comparability purposes with other HIAs and to avoid using further conversion factors. Indeed, older studies published estimates for PM_{10} while newer studies used $PM_{2.5}$, for which concentration surfaces and routine fixed monitor data are not yet available in the Barcelona metropolitan area. A comparison of US with European estimates for common pollutants showed that risk estimates were consistent between regions. For example, as reported in the French study [39], assuming black smoke (BS) to approximately reflect $PM_{2.5}$, the adjusted mortality risk ratio associated with a 10 µg/m^3 change in $PM_{2.5}$ was 1.06 (95%CI: 1.02-1.11) in one of the US studies [33] and 1.07 (95%CI: 1.03-1.10) in the French study. It should be noted, however, that recent new evidence on the association between long-term exposure to air pollution and the incidence of cardiovascular disease, including deaths, [54, 55] seems to indicate that the magnitude of long-term health effects may be larger than previously estimated. While this need to be verified with additional epidemiological studies, the CRF for total mortality may indeed be larger then the one used in this assessment. This was also the conclusion of an expert elicitation project conducted by the US EPA [56]. Thus, the total impact of exposure on mortality may have been underestimated in the CREAL risk assessment.

The magnitude and range of CRF's for asthma attacks is confirmed in several studies, thus uncertainties play a less dominant role. In contrast, larger uncertainty exists around the estimates for CB because it is based on only one CRF taken from an US study [26]. Risk estimates derived from this same US study also reported slightly lower as well as substantially higher estimates, so the degree and direction of uncertainty cannot be specified. We emphasize that the prevalence of these symptoms has been shown to be associated with air pollution in several other studies such as in Switzerland [57], Germany [58], or among

European women [59], but there is so far only one cohort study providing a CRF for the incidence of CB symptoms – a more appropriate measure for the risk and benefit assessment. Future epidemiological studies may fill this gap and lead to changes in the HIA methods for estimation of the impact on chronic symptoms in adults.

Another type of uncertainty relates to the transferability of CRFs from studies conducted in settings other than the Barcelona metropolitan area. For some outcomes, there are no studies available for Barcelona, thus comparability is difficult. For outcomes with estimations available from Barcelona, we generally choose a CRF representing a pooled estimate from various cities which are usually more precise than estimates taken from a single location. Acute effects of pollution on mortality have been undertaken in Barcelona. These studies confirm the general magnitude of the effects, although some estimates appear to be slightly higher in Barcelona [32]. This may be due to higher exposure of the population due to the type of residential development in this area. Other factors that may influence these results include difference in weather, housing characteristics, time spent outdoors, exercise and diet, smoking status, socio-economic status, and access to health care. Also, the possible presence of particularly susceptible subgroups (i.e. elderly, asthmatics) in the population under study compared to the population for which the CRF was derived may also affect the size of the estimate. Thus, given the slightly larger effects observed in Barcelona studies, our choice of pooled CRF may contribute to some underestimation of the acute effects on mortality.

5.3 Health outcomes

While chronic conditions and premature mortality account for the majority of health effects related to air pollution, other outcomes may be related to air pollution. Certain clinical outcomes such as changes in lung function, physician visits, missed school days, restricted activity days, or emergency room visits were not included in the evaluation and thus, an underestimation of the total benefits could be expected. Some of these outcomes, however, may be reflected in the estimates for the outcome included in this study. For example it is likely that persons visiting the emergency room would end up being hospitalized. Also, it is very likely that asthmatic children that experience acute asthma symptoms are also those more likely to require medical care. Moreover, reduced lung function – not considered in this impact assessment - is a strong predictor of life expectancy which in turn is part of our assessment. Similarly, no separate estimates are provided for lung cancer; however, the impact shown for total mortality is likely to include lung cancer cases as this disease continues to have very high mortality rates.

The overall benefits are likely to be underestimated for less severe outcomes. These outcomes could have been captured by evaluating social indicators such as loss of work days and restricted activity days. This was not evaluated in this phase of thisproject due to the lack of local data based on definitions for these indicators that match sufficiently those of the CRFs. Table 5.2 presents a list of outcomes associated with air pollution evaluated in this assessment and those omitted. It should be emphasized that evidence of a causal association with air pollution for some of these outcomes is still weak (i.e. reproductive outcomes), and that further research is needed to understand the degree of impact of air pollution.

We have assumed that ambient air pollution is a risk factor for acute exacerbations of asthma only. While not yet conclusive, several studies suggest that air pollution, in particular emissions from traffic, may lead to the onset of asthma in children. In particular, children living in proximity to busy roads appear to have higher rates of asthma [5]. Under this model, the overall public health benefits of the combined acute and chronic effects would be greater than those presented herein. The same case may apply to other chronic conditions such as chronic obstructive pulmonary disease or atherosclerosis. While it is not yet clear whether air pollution is an underlying cause for the development of these diseases, preliminary animal and human studies support this hypothesis.

Health outcomes related to the number of asthma attacks and acute bronchitis in children had to be extrapolated from studies conducted in neighboring countries. The comparison of the frequencies of related health outcomes for which data in Barcelona and other European countries are available, show that Barcelona is within the range of variation observed in Europe. For example, prevalence of chronic bronchitis in adults in ECRHS I in Barcelona was 2.3% compared to an average of 3.2% (95%CI: 1.17%-7.59%) for all cities. In Basel, the prevalence was 2.03%. Thus, it can be assumed that the frequency used for these outcomes would fall within the expected range of variability. In general, the attributable burden appears to be very large in case of bronchitis symptoms in children. There are however at least two 'intervention studies' confirming that a reduction in ambient PM due to abatement policies did result in very substantial decreases in the prevalence of these symptoms. Parallel reductions of air pollution and symptoms have been shown in Switzerland and in communities of former parts of East Germany [60, 61].

Definitions of the health end-points may vary from study to study, adding to the uncertainty in both the CRF and the assumed background frequency of the condition in the population. The latter very substantially determines the number of attributable cases. This may be specifically relevant for outcomes relating to asthma attacks and bronchitis symptoms in children for which it may be difficult to separate both outcomes. In general studies for which the CRF were derived and studies for which the frequency was obtained used similar international standardized questionnaires. For example most studies investigating asthma and asthma in symptoms in children and adults use the International Study Asthma and Allergies in Childhood (ISAAC) questionnaires. However, it is possible that some mismatch of definitions may exist with a potential for minor under or overestimation of results.

In addition to the uncertainty due to the lack of CRF estimates, the estimate of the CB is also heavily affected by the choice of the baseline incidence. For consistency we used an incidence based on the ASHMOG study from which the CRF was obtained. It has been suggested, however, that the net baseline incidence from this cohort study may overestimate true incidence because of remission of the diseases or some change in uncontrolled factors influencing the response during cohort follow-up [62]. We present impact on estimates taking into account remission rate in the sensitivity analysis, using a baseline incidence of 0.378% per year as proposed in CAFE-CBA.

Although rates of CB for Barcelona are available from ECRHS study, we have preferred using the ASHMOG incidence rate to avoid mismatch in definitions and non transferability between populations. The ECHRS study was composed of two parts. ECRHS I was a survey of young adults aged between 20 and 44 years that were selected at random from around 140,000 individuals and used to estimate variation in prevalence of asthma, and asthma-like symptoms. Several centers across Europe and other parts of the world took part including Barcelona. ECRHS II was a follow-up study after nine years aimed at estimating the incidence and prognosis of allergy, allergic disease (asthma, COPD, hayfever and eczema) and low lung function in adults. When using a definition of CB in ECRHS [59] as close as possible to the definition used in Seventh Adventist study [26] namely "usually cough during the day or night during winter" and "cough like this for as much as 3 months each year", the net incidence change (the net difference in the CB prevalence between ECRHS I and II) was 1.81% among never smoker, or a rate of 0.18% per year, which suggest possible overestimation of the results presented for CB.

At the current stage it is not possible to clearly argue for one or the other choices and approaches, thus uncertainties are substantial. It should be emphasized that this is of concern in this assessment especially for the monetary valuation, because CB is the second most important fraction in the cost estimates (see section 6). Ideally, definitions of morbidity (and its severity) should all be consistent across the epidemiological study used for the CRF, the health impact assessment calculations, and the derivation of costs. This can, however, to date not be accomplished without uncertainties. While the association between pollution and CB may be similar for all levels of severity, restriction of the risk assessment to more sever cases of CB would lead to a reduced burden while inclusion of less sever phenotypes of CB would lead to a much larger burden. Given that costs depend on severity of the diseases, the largest uncertainty in the CB results relates to the monetary evaluation.

Finally, based on the above discussions we emphasize that uncertainties in risk assessments for cardio-respiratory morbidity are by default larger than for mortality and health care use due to the lack of morbidity registries and different options to define morbidities. Health monitoring projects could substantially enhance the ability to estimate public health risks of various exposures.

Table 5.2. Health outcomes relevant for health impact assessment of air pollution.

	Evaluated in this assessment
Acute outcome	
Daily mortality	√
Respiratory hospital admissions	√
Cardiovascular hospital admissions	√
Emergency room visits for respiratory and cardiac problems	--
Primary care visits for respiratory and cardiac conditions	--
Use of respiratory and cardiovascular medications	--
Days of restricted activity	--
Work absenteeism	--
School days missed	--
Self-medication	--
Avoidance behavior	--
Acute symptoms	√
Physiologic changes, e.g. in lung function	--
Chronic disease outcome	
Mortality from chronic cardio-respiratory disease	--
Chronic respiratory disease incidence and prevalence (asthma, COPD)	√ (bronchitis)
Chronic change in physiologic function (i.e. lung function)	--
Lung cancer	--
Chronic cardiovascular disease	--
Reproductive outcomes	
Pregnancy complications	--
Low birth weight	--
Pre-term delivery	--
Cognitive development in infants	--

5.4 Population exposure

We used modeled PM_{10} concentration maps to estimate the population weighted-average concentration instead of an average concentration detected at a single fixed-monitor. Compliance with EU limit values by regulatory authorities are estimated by averaging all cells of the grid from this same map and determining if the average is equal or below the EU limit. This approach is consistent with the approach used to estimate changes in exposure used in this HIA.

Modeled surfaces were validated by comparing concentration levels at fixed monitoring sites with predicted concentrations. Except for some locations, surface map concentrations predicted adequately concentration levels at fixed monitors.

Table 5.3 presents annual mean concentrations for 2004 as measured at fixed monitoring locations of different municipalities of study area. The greatest differences were detected near industrial hot spots, for which assumptions made during the modeling step may not have been entirely adequate. Because industrial areas are also less populated areas, impact on estimates are considered minor. Other European HIAs (i.e. ENHIS) have used measurements at one single urban background monitor to represent exposure concentrations in Barcelona. We believe that the population weighted concentrations developed for this HIA represents the population exposure in the Barcelona metropolitan area more adequately than any fixed site monitor because it takes into account the population distribution in the area, thus, giving more weight to areas where a lot of people live as compared to less populated regions.

Table 5.3. PM_{10} annual mean concentrations for fixed site monitors located in municipalities of the study area (year 2004).

Municipality	Monitor site	Annual mean PM_{10} (µg/m^3)
Barcelona	Dàrsena sud	56
	Eixample	55
	Gràcia-St Gervasi	50
	Plaça Universitat	46
	Port-Edifici Estilbarna	47
	Sants	52
	Zona Usniversitària	34
Prat de Llobregat		44
Esplugues de Llobregat		43
Hospitalet de Llobregat		34
Molins de Rei-ajuntament		44
Sant Adrià de Besòs		52
Sant Feliu de Llobregat		45
Sant Viçenç dels horts		49
Santa Coloma de Gramenet		26
Barberà del Vallès		54
Castellbisbal	Avda. Pau Casals	37
	Mirador del Llobregat	36
Granollers		53
Martorell		39
Montcada		45
Montornès del Vallès		39
Montornès del Vallès		26
Pallejà		47
Rubí		39
Sabadell	Escola industrial	37
	Gran Via-Crta. De Prats	47
Sant Andreu de la Barca		46
Sant Cugat del Vallès		39
Santa Perpètua de Mogoda		57
Terrassa		46
2004 annual mean		**44**

Source: [8]

Another important limitation is the use of PM_{10} as a marker for pollution and a surrogate for other pollutants in the atmosphere. There may be other pollutants that may or may not be only partially captured by the effects of PM_{10}, which could have resulted in some underestimation of effects. Ozone (O_3) is an example of a pollutant not highly correlated with urban PM, and with well established health effects. Thus, some HIA derive the burden and benefits for O_3 as well.

Finally, Barcelona has extremely high traffic density coupled with one of the highest population densities in Europe, suggesting high traffic related exposure. For example, source apportionment studies in Barcelona have shown that at least a third of all PM_{10} generated in Barcelona are due to traffic emissions [24, 63] but that this contribution could be even higher when considering indirect effects of traffic such as road re-suspension (i.e. tire rubber). It has recently been estimated that about 40% to 45% of PM_{10} and $PM_{2.5}$ concentrations in Barcelona were generated by traffic [13, 64]. In other words, many people live, work, and spend their time very close to street traffic, where PM concentrations are much higher. More recent research suggests a detrimental role of those pollutants that occur in very high concentrations within the first 50-100 meters along streets [5, 6]. Traffic proximity distributions are currently not available for Barcelona, thus, this newest evidence could not be used in this risk assessment. The health burden due to traffic is, however, expected to be clearly underestimated by this assessment. The future availability of concentration surfaces for $PM_{2.5}$ or even the finer fraction of PM such as ultrafine and data regarding the distribution of distance to main roads and traffic density would be an important contribution for the development of health impact assessment that target more specifically traffic-related exposure.

5.5 Sensitivity analysis

Table 5.4 presents the percent change of the mean health benefit estimates under various alternative assumptions regarding the input data. This sensitivity analysis evaluated the impact on estimates of the variability of the CRFs (95%CI), the use of alternative CRFs, and the use of different frequencies of outcomes.

As mentioned in the discussion, the range of estimates provided is uniquely based on the uncertainty around the CRFs. Depending on the health outcome considered these upper and lower limits fall within ±30% and ±80% of the central estimate, The highest range refers to the CRF for CB in adults. For other outcomes, including mortality, the range of uncertainty is lower and averages approximately ±40% around the mean estimate.

We have used a set of CRFs that may sometimes differ from other risk assessments in Europe. For example, more recent CRFs for mortality exist than the one used in this evaluation, such as the extended analyses of the ACS study [36]. The ACS extended study provides estimates for the period of study 1979-83, the lowest estimate, period 1999-2000, and an estimate for an average of both. The average estimate has been used in CAFE-CBA, for example, and is becoming the standard in HIAs. The sensitivity analysis shows that using the lowest CRF estimate from ACS would provide a mean estimate about 50% lower than the current estimate but that using the average ACS CRF estimate provides estimates similar than those obtained with the CRF used in this evaluation. In contrast, using a CRF function from a recent ACS analysis based on the Los Angeles population [55], the estimates would be about 120% higher than those presented herein. It is not clear whether those results apply better or worse to the Spanish population then the general ACS estimate used in our project. It is of note, however, that the Los Angeles based analyses used a far more sophisticated individual level exposure assignment and one reason for the much larger CRF may be this improvement in exposure assessment. The Jerrett et al study is certainly one of the reasons leading to the conclusions of experts that effects of air pollution on mortality might have been underestimated in previous ACS studies [56]. Further research is needed for a better understanding and precision of the magnitude of chronic effects due to air pollution, and to reduce uncertainty in the risk assessment evaluations.

For acute effects on mortality and hospital admissions, we have used CRF pooled estimates derived from multicenter studies. Results using the city specific estimate for Barcelona provided in these studies show that the mean estimate for total acute mortality and hospital admission could be substantially higher (40%-50%,) but lower (20%) for cardiovascular hospital admission, and suggest that using pooled estimates may provide a balanced picture. Further research is needed to understand the determinants of risk differences between populations.

We used a CRF function for CB slightly bigger than in CAFE-CBA, but the sensitivity analysis shows that the impact on the mean estimate is small. Not shown but worth mentioning, is that this other CRFs presents even a larger range of uncertainty than the CRF used in this study, with a negative lower confidence interval. However, inclusion of a CFR with a lower bound value at zero or even at a negative level implies that adverse effects, no effect, or protective effects of air pollution are all possible. We prefer to restrict HIA to outcomes for which experts would agree to be affected by pollution. Chronic bronchitis symptoms belong to this list, thus the lower bound of the estimate ought to be larger then zero.

For other morbidity outcomes such as for acute bronchitis in children and asthma attacks in adults and children, the variation in CRFs is smaller and include the CRF used in the CAFE-CBA.

We occasionally used population frequencies based on populations other than Barcelona. Independently of the scenario evaluated, the change in estimation is proportional to the error in the frequency that could have been made. An error of 20% around the frequency estimates would impact the mean estimates by this same amount. Thus, uncertainties due to this factor are of minor relevance.

As presented earlier, the estimation of the baseline frequency of new onset of CB is not straightforward and different assumptions have been used in different risk assessments. In this sensitivity analysis we used a baseline incidence rate for CB that takes into account remission following the approach taken by CAFE-CBA. The result of this sensitivity analysis show that this factor would reduce the mean estimate by about 20%.

Finally, we used a population exposure concentration that may present some error because of the models used to develop surface maps and because details regarding the population distribution are lacking. If one assumes the error to be present only in the current estimates of exposure surfaces while no error is assumed at the measure of the compliance level, this would imply that an over or under estimation of the current population mean exposure by +/-5 $\mu g/m^3$ would affect the main results by ±15%, for the WHO scenario for example. However, in reality these uncertainties have far less impact on the estimates when considering future exposure scenario, because one can expect that the same errors and uncertainties would apply to the derivation of the exposure estimate.

Table 5.4. Sensitivity of the mean estimation of air pollution attributable number of cases due to uncertainties of main input data.

Outcome	Criteria for sensitivity analysis	% change in mean estimate
Deaths		
Cumulative long-term deaths	Lower/Upper 95% CI value of CRF	+/-37%
	Mean value of CRF from ACS study extended analyses, low estimate (1979-1983)*	-52%
	Mean value of CRF from ACS study extended analyses, average estimate *	-7%
	Mean value of CRF from ACS Los Angeles†	+118%
Immediate acute deaths	Lower/Upper 95% CI value of CRF	+/-33%
	Mean city specific CRF for PM_{10} RR=1.00932 (1.00567-1.01299) per 10 µg/m^3 from [27], Annex 4	+55%
Infant deaths	Lower/Upper 95% CI value of CRF	+/-50%
Hospital admissions		
Respiratory	Lower/Upper 95% CI value of CRF	+/-45%
	Mean city specific CRF for PM_{10} RR=1.0193 (1.0101-1.0285) per 10 µg/m^3 from [16]	+42%
Cardiovascular	Lower/Upper 95% CI value of CRF	+/-49%
	Mean city specific CRF for PM_{10} RR=1.005 per 10 µg/m^3 from [30]	-18%
Morbidity		
Chronic bronchitis in adults	Lower/Upper 95% CI value of CRF	+/-79%
	Same CRF as used in CAFE-CBA, RR=1.07 (0.995-1.143) per 10µg/m^3¶	-24%
	Incidence of bronchitis symptoms based as in CAFE-CBA that takes into account remission (0.378%)	-24%
Acute bronchitis in children	Lower/Upper 95% CI value of CRF	+/-37%
	Same CRF as used in CAFE-CBA for chronic cough, RR=1.027 (1.025-1.596) per 10 µg/m^3 (PM15) from [44]	-8%
	% with bronchitis +/-20% HIA estimate	+/-18%
Asthma attacks in adults	Lower/Upper 95% CI value of CRF	+/-48%
	Same CRF as used in CAFE-CBA for Lower respiratory symptoms, RR=1.041 (0.99-1.09) per 10 µg/m^3 from [47]	+5%
	% asthmatics or asthma attack in adults+/-20% HIA estimate	+/-20%
Asthma attacks in children	Lower/Upper 95% CI value of CRF	+/-36%
	Same CRF as used in CAFE-CBA for Lower respiratory symptoms, RR=1.04 (1.0226-1.0593) per 10 µg/m^3 from [65]	-2%
	% asthmatics or asthma attack in children +/-20% HIA estimate	+/-20%

CRF : concentration-response function;
** [36], $PM_{2.5}$ (1979-83)=1.04 (1.01-1.08) per 10 µg/m^3, transformed to PM_{10}=1.02 (1.01-1.05) per 10 µg/m^3 ; $PM_{2.5}$ (average)=1.06 (1.02-1.11) per 10 µg/m^3; transformed to PM_{10}=1.04 (1.01-1.07) per 10 µg/m^3*
† [55] RR $PM_{2.5}$=1.17 (1.05-1.30) per 10 µg/m^3; transformed to RR PM_{10}=1.10 (1.03-1.18) per 10 µg/m^3
¶[66]

5.6. Time between air quality improvement and public health benefits

Not all the expected benefits of improved air quality will immediately materialize. In general, acute effects of pollution are expected to be reduced in parallel to the improvements of air quality. A recent intervention study confirms immediate and sustained reductions in mortality rates following the ban of coal use in the city of Dublin [67]. The intervention was implemented as of 1991. Annual mean pollution immediately dropped by some 20-30% and mortality decreased as promptly by some 15-20%. However, for consequences of air pollution that are a combination of both acute and chronic effects, it is likely that full health benefits may take a few years to attain [68]. Also, there may be competing risks factors or changes in existing risk profiles that may in the long run interfere with long-term benefits. Thus, uncertainties for long-term impacts and benefits are larger then those in the acute effect domain.

This dynamics of time dependent processes can be described with a hypothetical example using the results of our Barcelona study. If average PM_{10} levels in Barcelona were immediately changed from 50 to 20 µg/m^3 as of January 2011, one would expect the 2011 deaths toll in Barcelona to also immediately drop by at least 520 cases (or 2% - see **Table 4.1**, 'acute effects'), corresponding to, on average, 10 fewer death per week.

While the number is most likely larger, it would be very unlikely that the number of death fell by the total number of 3,500 cases (shown in **Table 4.1** total effects) already in 2011 as part of those are accounted for a reduction in the development of chronic pathologies. A likely scenario is that the death toll will fall by more then the 520 'acute effects' but less then the 3,500 in the very first year of an immediate change of the annual mean by 30 µg/m^3. The exact time pattern of these benefits is not known. According to an estimation model recently proposed [68], one would expect some 40% of the total annual death benefits to materialize already in the first year (i.e. 40% of 3,500, or 1,400 death).

Note that the hospital admissions, acute bronchitis in children, and asthma related problems shown in **Table 4.1** all reflect acute effects as a consequence of rather short-term exposures. Thus, the benefits of reduced air pollution are expected to materialize immediately and remain on a lower level as long as pollution is kept lower.

As air pollution is unlikely to drop immediately but rather gradually once policies are implemented, changes in mortality and morbidity are expected to happen gradually as well. To observe (or monitor) such gradual benefits of air pollution policies is far more difficult than assessing changes that happen as a consequence of immediate and drastic declines in pollution. However, with large enough studies and observation periods covering several years, it may be possible to confirm improvements of health due to clean air policies with gradual improvements. A few studies mainly investigations conducted in Switzerland, former Eastern Germany, and within the Souther Californian Children Health study were able to demonstrate the reduction of health problems to parallel periods of changes in air quality due to policies or due to moving to another location.

5.7. Comparison with other risk factors

It is worth considering the impact of air pollution and thus the benefit of air quality managements in context with other health problems. While the relative risk of pollution on health of an 'average person' is expected to be small and in any case substantially smaller then the adverse effects of smoking, it is important to understand that the overall impact of pollution on public health is in fact large due to the widespread exposure to pollution. Thus, in contrast to – e.g. – smoking, we emphasize that 100% of the population is exposed to air pollutio. O nly some 25% of people in Catalonia choose to smoke these days while nobody can escape exposure to some levels of poor air quality.

Nevertheless, the total health burden of smoking – even with only 25% active smokers – is still expected to be larger than the burden due to air pollution. This is due to the extremely high risks related to active smoking. For example, one of the studies used to estimate the long-term effect of air pollution [33] also provided the estimate of death among smokers. While a 10 µg/m^3 increase in PM_{10} was associated with a ~4% increase of death, smokers had a 100% higher risk of death during the follow-up period. Another important death toll relates to traffic accidents. While trends are decreasing, there are still some 500 death due to car accidents in Catalonia every year. As shown in our report, the death toll due to air pollution being above EU standards is some 2-3 times larger than the toll due to traffic accidents This is in line with previous studies [15, 69]. A report prepared for the WHO [69] also compared life years lost due to air pollution as compared to traffic accidents. Although accident victims are used to be far younger then those dying due to effects of air pollution, the effect of air pollution on life expectancy was substantially larger then the effect of accidents. However, traffic accidents are also a cause of very substantial life-time morbidities with further adverse effects on life expectancy. These have not been included in the [69] assessment. To juxtapose air pollution and traffic accidents is in fact of interest in the evaluation of some air quality policies. Given the dominant role of traffic as a source of air pollution, some measures of air quality improvements such as speed limitations or closure of streets for traffic in densely populated areas can have beneficial effects on both air quality and traffic accidents. Thus, the evaluation of air quality policies need to be put in broader context beyond the direct effects on air quality to identify complementary benefits. As noted by WHO [70], policies affecting traffic will overlap in terms of health benefits with policies of air pollution, climate change, accidents, physical activity, and noise.

We have determined that the increase of the life expectancy considering a reduction of air pollution to levels protective to public health could be around one year. According to statistics from the Insititut d'estadística de Catalunya [53], the life expectancy in Catalonia at birth was 80.75 years in 2004 while it was more than one year inferior in the year 1997 and about three years less in 1992. Reduction of air pollution could accelerate the rate of increase in life expectancy that the society is already experiencing due to continuous improvements of the social context.

6 Monetary valuation of health benefits

6.1 Introduction

The use of monetary valuations of air pollution abatement strategies has been the subject of much debate in recent years because of the ethical considerations related to translating health benefits into costs that would be intangible for the population. However, every society has only limited resources to allocate to projects and cost-benefit analysis based on monetary valuation of health benefits is often required by policy and decision makers to help take decisions on suitability or prioritization of public policy development and plans.

In this section we provide monetary valuation for the health benefits that could result from a reduction of air pollution in the Barcelona metropolitan area.

We present results based on two types of valuations. Core results are based on assigning monetary value to the attributable numbers obtained from previous sections. We name this part the "VSL approach", in reference to the method used to value the cost of death, the Value of Statistical Life-VSL, an approach commonly used in other economic HIA in the US [71]. However in view of recent concerns of the adequacy of the "attributable death" concept, we present in the discussion section a justification for a different approach (VOLY approach), and a comparison of monetary results.

6.2 Monetary measures-VSL approach

Because there is no market price for benefits resulting from cleaner air, economists in different settings have attempted to develop alternative measures of value. Ideally measures of value should represent all the losses to individuals and to society that result from adverse health effects, and reflect preferences and decision-making processes similar to those of daily life.

There are two generally accepted values of changes in well-being due to reducing the adverse health effects of air pollution: the cost of illness (COI) measures and the willingness to pay (WTP) (or willingness to accept, WTA) measures. The COI requires calculating the actual direct expenditures on medical costs, plus indirect costs (lost wages), incurred due to illness. WTP (and WTA) are derived from market choices that reduce risk to health or life indirectly. Values derived from this method are based on relating differences in wages or consumer costs to differing degrees of risk. When values inferred from markets are not available, another means to estimate value involves the use of surveys. This method is referred as contingent valuation because people are asked to determine what something would be worth as if they were able to purchase or sell it.

As discussed in previous sections, premature long-term mortality (attributable death) is the most severe effect of exposure to air pollution. The determination of an appropriate value to attach to a reduction of the risk of death is thus the most influential piece in monetary valuations. To be consistent with the valuation developed in CAFE-CBA, an important cost-benefit analysis on air pollution reduction in Europe, we used monetary values proposed in CAFE-CBA that were developed by ExternE, a research project of the European Commission on external cost for energy within the project NewExt (New Elements for the Assessment of External Costs from Energy Technologies). This group developed monetary values for attibutable deaths following WTP approach. WTP was based on the determination by individuals, on the basis of budget and preferences, what he or she is willing to pay to reduce the mortality risk, measured as the "value of statistical life" (VSL). The VSL is thus derived from the small difference that the 'average interviewed person' is ready to pay to reduce risk to a defined level, aggregated across the total population, and expressed as the value to prevent one single death. In other words, study participants are not asked the value of life but of a reduction of the risk of death.

For other endpoints, several accepted values have been developed in the last decade and have been widely used in cost-benefit analysis. For consistency with collaborative European assessments, we used final monetary values proposed in CAFE-CBA, that were derived by ExternE and were mainly based on an empirical study covering five studies across Europe [20]. As for mortality, the monetary value for morbidity attempted to include the sum of the following three independent components:

Resource cost: i.e. medical costs paid by the health service.

Opportunity costs: i.e costs in terms of loss of productivity and the opportunity cost of leisure including non-paid work.

Dis-utility costs: i.e other social and economic costs. This is reflected in a valuation of the WTP, to avoid or compensate for the loss of welfare associated with the illness.

Table 6.1 presents a summary of the monetary values proposed by CAFE-CBA for the outcomes under consideration in this evaluation and transformed in 2006 price year. Aggregated monetary benefits as presented in **Table 6.2** were obtained by multiplying the monetary value by the number of health benefits for each outcome. The range of values for premature mortality and CB corresponds to the mean and median values. For simplification, we calculated costs using the average value for 2006 price year of the range shown. The total number of symptoms refers to the sum of the number of asthma attack in children and adults. CB was only considered for adults.

Table 6.1. Values to monetize the effects of reducing air pollution

Health outcome	Value in Euros (as published in CAFE, 2005)	Value in Euros (2006 price-year)*
Attributable deaths	€980,000-€2,000,000/death	€1,020,000-€2,080,000/death
Respiratory and cardiac hospital admissions	€2,000/admission	€2,100/admission
Chronic bronchitis	€120,000-€250,000/case	€125,000-€260,000/case
Symptoms days	€38/day	€39/day

**From real gross domestic product average annual increase for 2006 in Spain: 3.9% (Source:Eurostat); €: Euros*

6.3 Results based on the VSL approach

Table 6.2 presents the results for the monetized benefits obtained by health outcome and aggregated benefits. Estimates are presented with a 95% confidence interval (95%CI) obtained by using mid monetary values applied to the confidence intervals of the health outcomes benefits derived from previous sections.

For the scenario considering a reduction of annual average PM_{10} levels to 20 µg/m^3, results show that the estimated total aggregated cost benefits range between 3,500 to 9,000 million Euros (mean 6,400 million Euros) with per capita benefits of 1,600 euros (95%CI: 870-2,300) per year.

Separated by health outcomes, results confirm that more than 80% of the costs are due to the number of premature deaths estimated that could be prevented annually by this air pollution reduction. The second most outcome contributing to costs is CB (only adults considered), representing about 15% of the total estimate.

When considering a reduction scenario of annual average PM_{10} levels to 40 µg/m³ as in the intermediate scenario, benefits would be approximately one third of those presented for the WHO scenario, with annual per capita benefits of some 600 Euros.

Table 6.2. Monetized benefits per year for air pollution decrease in Barcelona metropolitan area by health outcome (VSL approach)

Health benefits	PM_{10} annual mean reduction to 20 µg/m³			PM_{10} annual mean reduction to 40 µg/m³		
	Number of health benefits (95%CI)	Monetized benefits per year		Number of health benefits (95%CI)	Monetized benefits per year	
Mortality						
Attributable deaths	3,500 (2,200-4,800)	5,400 (3,400-7,400)	Mio. Euros	1,200 (760-1,700)	1,900 (1,200-2,700)	Mio. Euros
Morbidity						
Hospital admissions	1,800 (950-2,600)	3.7 (2.0-5.4)	Mio. Euros	600 (320-890)	1.3 (0.7-1.8)	Mio. Euros
Chronic bronchitis (adults)	5,100 (550-8,500)	970 (100-1600)	Mio. Euros	1900 (190-3,400)	360 (40-700)	Mio. Euros
Total symptoms	54,000 (27,400-75,700)	2.1 (1.1-3.0)	Mio. Euros	18700 (9,300-26,800)	0.7 (0.4-1.1)	Mio. Euros
Total monetized benefits	Total (approach VSL)	6,400 (3,500-9,000)	Mio. Euros	Total (approach VSL)	2,300 (1,200-3,300)	Mio. Euros
	Annual per capita benefits[1]	1,600 (870-2,300)	Euros	Annual per capita benefits[1]	570 (300-830)	Euros

Notes:
Mio. Millions
1. Calculated for population of the study area of 4 million habitants

6.4 Discussion of monetary evaluation

Based on the VSL approach, this assessment suggests substantial annual benefits in terms of cost for reducing air pollution in the Barcelona metropolitan area.

Comparison with other estimates shows that the VSL value proposed in CAFE-CBA and used in this assessment is consistent with other evaluations but slightly lower than the VSL proposed by other leading agencies in the US. For example a recent economical evaluation in California [72] used a VSL of $6.7 million (~4.9 million Euros, price year 2006) based on the most recent final EPA regulatory analysis [71]. This same evaluation also provided a cost of $374,000 (~270,000 Euros, price year for 2005) per case of CB, similar to the range used in this evaluation. In this report from the US, costs for other outcomes were also similar to those proposed by CAFE-CBA.

As already emphasized in previous sections, the evaluation of morbidity and mortality come with inherent uncertainties, which were particularly large for CB. We emphasize that all uncertainties are propagated into the monetary evaluation, which in itself comes with a range of possible values.

The results of this monetary valuation have confirmed that the total costs are driven by yearly attributable deaths. As introduced in section 3.4.2.1, the concept to derive “attributable deaths” raises inherent questions. An in-depth discussion of these limitations and of alternative method are presented within the CAFE-CBA and are detailed in addition in a methodological paper [42] and report [69]. The following paragraphs present an overview of these limitations as discussed in these reports, and present results of an alternative method to derive monetary benefits based on this recent information.

6.4.1 Use of life tables in air pollution health impact assessment

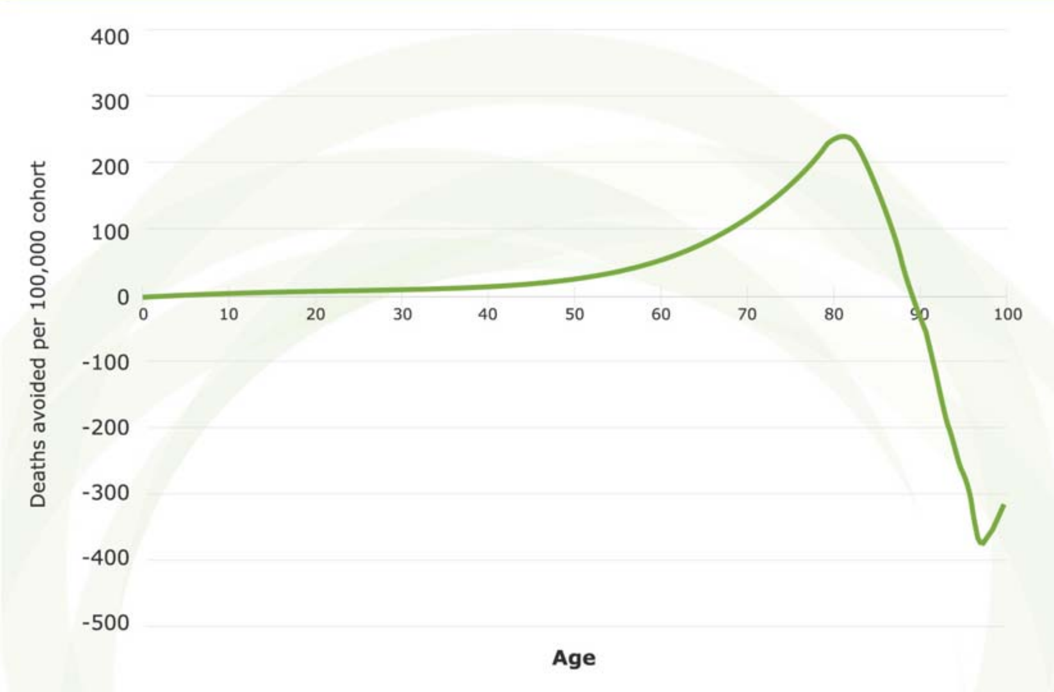
In section 4.1.2, we have presented the average gain in life expectancy in months that would be experienced by our 2004 population if air pollution was reduced by the scenarios considered. The derivation of this number is based on life tables. In brief, life-table methods predict the pattern of survival, life-years (LY) lived and deaths for a cohort. In this HIA, for example, we used our current 2004 population data and observed 2004 hazard rates (mortality rates) to derive a survival curve for this cohort that we applied to this same population to estimate the changes in population structure as the cohort ages. From this survival curve one can extrapolate the number of deaths expected at each age group, the total life expectancy of the cohort, or the total number of LY of a study population.

To obtain gains or losses due to changes in air pollution levels, two survival curves are derived and compared. One curve is derived using current hazard rates (baseline scenario) and one using hazard rates expected after a reduction of air pollution (altered scenario). In our assessment the altered scenario is obtained using the CRF for chronic mortality described in section 3.4.2.1 for the population with ages above 30 and scaled for the scenario under consideration. The results expressed in an HIA based on life tables are thus expressed as a change (gain in our assessment) of LY that derive from a difference between the baseline and altered scenario.

6.4.2 Life years versus attributable deaths

As we have done in our assessment, most HIA are interested in expressing results annually. In previous sections, the benefits in deaths (and other outcomes) were calculated for one year of change going from the baseline to an altered scenario and were considered as "attributable deaths" due to this reduction. In the first year of a reduction scenario, the use of life tables and the derivation of attributable death as done in this project would lead to the same results. Under real world policy scenario it is usually assumed that the air pollution reduction was sustained, thus, compared to a baseline situation of no change one expects benefits to repeat each year. However, to express such benefits in the long run – for example across the lifetime of a cohort – the two approaches would lead to increasingly discrepant results, and one would in fact notice that the concept of annual 'attributable death' becomes flawed as the years pass. Indeed, if one follows a birth cohort until extinction, everybody dies no matter how clean the air is, and thus there is no deaths avoided. This is illustrated in Figure 6.1 (top) for our 2004 population assuming a decrease in hazard rates for meeting the WHO scenario. This figure shows that although the gain in the number of death due to the reduction of air pollution increases with age, it reaches a limit and becomes negative for older ages. This is because "the total number of deaths in the baseline and the altered scenario must equal the size of the starting population, so any difference in numbers of deaths at one age must be cancelled out by other ages and the net effect on total numbers of deaths must be zero", quote from [69]. In other words, removal or reduction of a risk factor, e.g. air pollution, postpones the time of death but it does not prevent death.

Based on this consideration, CAFE-CBA and others have proposed that the impact of risk factors on mortality due to air pollution should be expressed as years of life lost (or gained for a reduction of air pollution) instead of attributable deaths, because LY accumulate independently of deaths. Indeed, as is shown in Figure 6.1 (bottom), when we consider life expectancy and the change of total number of LY lived under the baseline and altered scenario, one sees that gains in LY are obtained at each age, with all LY being positive. While all approaches come with inherent assumptions and extrapolations from the current situation to the unknown future, the LY concepts reflects in a more appropriate way the dynamics of life and death across time. To illustrate this we apply these concepts to our Barcelona air pollution HIA.



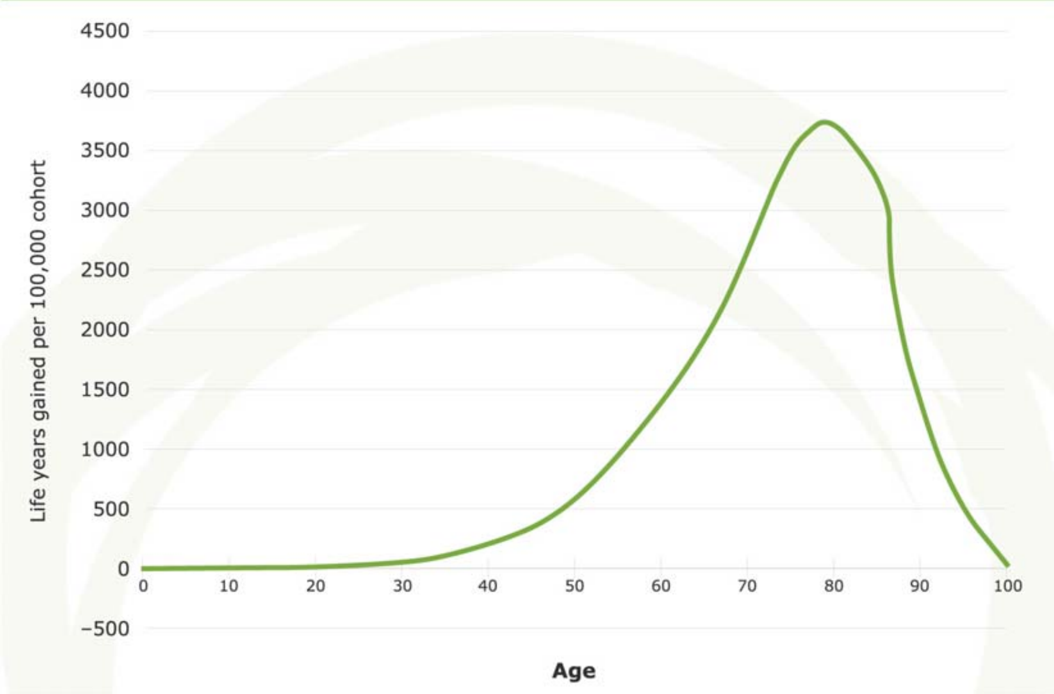


Figure 6.1. Death avoided (top) and life years gained (bottom) for a reduction in hazard rate corresponding to the WHO scenario applied to the 2004 population of the study area.

6.4.3 Life years gained

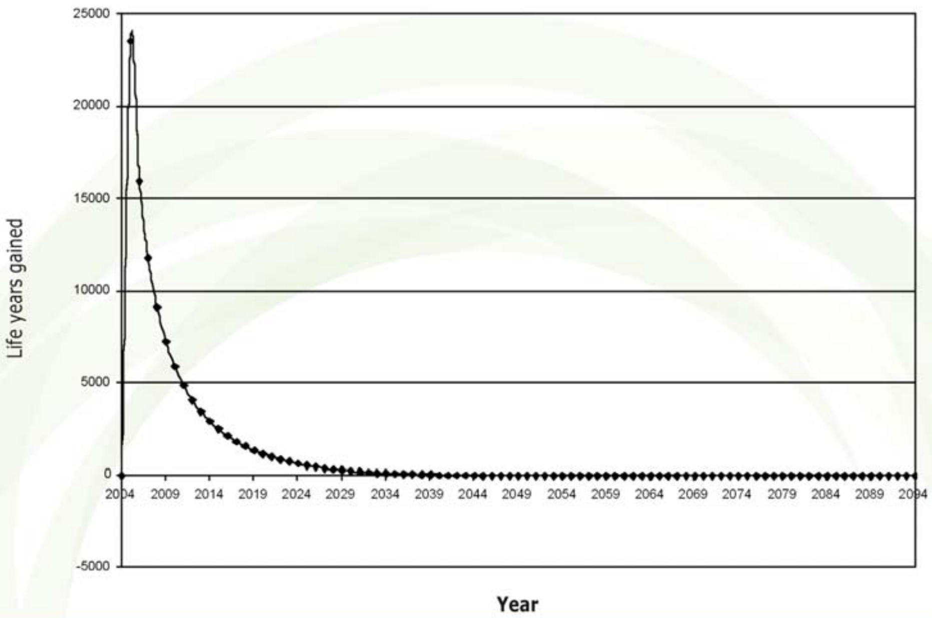
We derived gain in life years following the approach presented above as an alternative to annual attributable deaths. In brief, for each of the two survival curves (baseline and altered scenario) obtained for our study population, we multiplied the survival cumulative probability obtained through life tables by the number of individuals in each age group in our population and obtained LY lived by age group. Differences between the two curves were then summed to obtain total gains. Results of LY gained are presented in **Table 6.3**.

Table 6.3. Health benefits expressed as time gained for a reduction of PM_{10} annual mean in the Barcelona metropolitan area

Outcome	Unit	Age	Health benefits (95%CI)	
			Decrease to annual mean concentration of 20 µg/m^3	Decrease to annual mean concentration of 40 µg/m^3
Gain in life years	years	≥30	22,100 (13,700-30,700)	8,200 (4,900-11,500)

Because we were interested in annual benefits, we derived LY gained for the year following a change in hazard rate due to a decrease to air pollution (first year of decrease in air pollution). It should be emphasized that even if hazard rates returned to baseline levels in the following year, gains in life years would continue to accrue in following years. This is due to the change of the age distribution among the population at year one. This change affects the future years of life as well. Thus, total LY gained over the lifetime of the cohort is greater than presented in **Table 6.3**.

If air pollution reduction is sustained the future years lived among the cohort will further increase with gains being distributed far into the future until extinction of the cohort. **Figure 6.2** illustrates this point. The total LY gained for the cohort for a pulse or sustained reduction of air pollution during its lifetime would then be the integration of the surface under each of the curves. By dividing this cumulative LY by the total population of the cohort one could obtain the average increase of life expectancy for that cohort due to the reduction in air pollution.



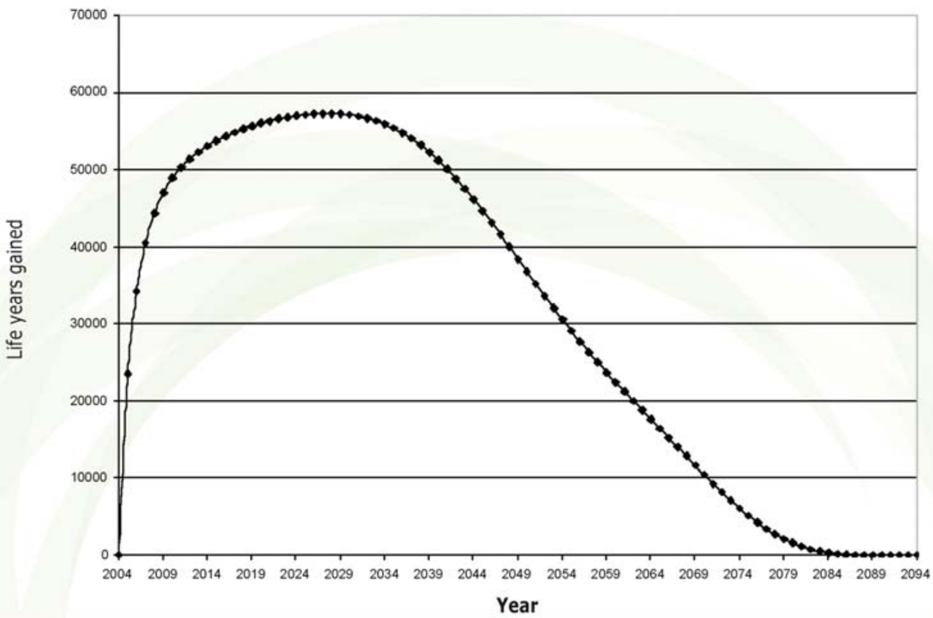


Figure 6.2. Gain in life years considering a one-year pulse of air pollution reduction (top) and a sustained reduction of air pollution (bottom). Both graphs assumed a reduction in hazard rate corresponding to the WHO scenario applied to 2004 population of the study area followed until extinction.

6.4.4 Monetary measure of life year

Monetary valuations based on LY use a "value of life year" (VOLY) to be attached to year of life year lost or gained. The range of monetary values adopted for VOLY's in the CAFE-CBA are presented in **Table 6.4**. These values were proposed by ExternE (REF) and developed based on recent empirical information derived from contingent valuations conducted in different areas across Europe. As for the VSL approach, we calculated costs using the average value for 2006 price year of the range shown in this table that corresponds to the study median (low estimate) and mean (high estimate).

Table 6.4. Values to monetize the effects of reducing air pollution expressed as life years

Monetary value	Range in Euros (as published)	Range in Euros (2006 price-year)*
VOLY	€52,000-€120,000	€54,000-€125,000

*From real gross domestic product average annual increase for 2006 in Spain: 3.9% (Source:Eurostat)

6.4.5 Monetary valuation using life years

Table 6.5 presents the results for the monetized benefits obtained for LY gained. As for the VSL approach, estimates are presented with a 95% confidence interval (95%CI).

For the scenario considering a reduction of annual average PM_{10} levels to 20 $\mu g/m^3$, results show that the estimated benefits range between 1,200 to 2,700 million Euros (mean 2,000 million Euros). Results for mortality using attributable deaths were on average 2.6 times larger than those based on the VOLY approach.

When adding the VOLY estimates to morbidity estimates, the total benefits reach 3,000 million euros (95%CI:1,300-4,400) representing per capita benefits around 740 euros (95%CI: 330-1,100). In this case the total results using attributable deaths were on average two times larger than using the VOLY approach. Due to the reduced weight of mortality in the VOLY approach, CB contributed 30% to the total estimates as compared to 15% with the VSL approach.

As before, one third of the benefits derived for the WHO scenario would already occur once PM_{10} levels reach the current EU target of 40 $\mu g/m^3$.

Table 6.5. Monetized benefits per year for air pollution decrease in Barcelona metropolitan area by health outcome (VOLY approach)

Health benefits	PM_{10} annual mean reduction to 20 µg/m^3			PM_{10} annual mean reduction to 40 µg/m^3		
	Number of health benefits (95%CI)	Monetized benefits per year		Number of health benefits (95%CI)	Monetized benefits per year	
Mortality						
Years of life gained	22,100 (13,700-30,700)	2,000 (1,200-2,700)	Mio. Euros	8,200 (4,900-11,500)	730 (440-1,000)	Mio. Euros
Morbidity						
Hospital admissions	1,800 (950-2,600)	3.7 (2.0-5.4)	Mio. Euros	600 (320-890)	1.3 (0.7-1.8)	Mio. Euros
Chronic bronchitis (adults)	5,100 (550-8,500)	970 (100-1600)	Mio. Euros	1,900 (190-3400)	360 (40-700)	Mio. Euros
Total symptoms	54,000 (27,400-75,700)	2.1 (1.1-3.0)	Mio. Euros	18,700 (9300-26800)	0.7 (0.4-1.1)	Mio. Euros
Total monetized benefits	Total (approach VOLY)	3,000 (1,300-4,400)	Mio. Euros	Total (approach VOLY)	1,100 (480-1,700)	Mio. Euros
	Annual per capita benefits[1]	740 (330-1,100)	Euros	Annual per capita benefits[1]	270 (120-420)	Euros

Notes:
Mio. Millions
1. Calculated for population of the study area of 4 million habitants

6.4.6 Other considerations

As discussed above, for mortality, monetary valuations based on life years instead of "attributable deaths" may conceptually be more adequate, in particular in the long term. Nevertheless, one should keep in mind that a decrease of air pollution would decrease mortality risks, thus initially decrease the absolute number of deaths per year in a population. This has in fact been observed for example in Dublin after the ban of coal or in the Utah valley during the one-year period of a shut-down of a steal mill. The mill was the main source of air pollution in the valley, thus pollutants dropped during the year of closure and increased again thereafter. Mortality and morbidity followed the same pattern.

In this section, we have illustrated a simple case, estimating gains in LY and costs based on a single cohort for an impact of a reduction in hazard rates for a first year of air pollution reduction.

Deriving benefits for longer period of time would need to take into account more complex assumptions. For example, if air pollution reduction is sustained, future cohorts to be born would also benefit from this reduction. Thus, the scenario of extinction of the cohort is not realistic. Moreover, all concepts assume that apart from air pollution all other health determining factors – including susceptibilities - in the cohorts to remain the same as those of the current cohorts.

Another important issue to consider when dealing with LY is weighting. For example, it has been suggested that the value of a LY should not have the same weight if lived earlier than later in life, although a lot of controversy still exists around this approach because surveys have shown that older people value life as much as younger persons [20, 62]. Adjusting LY to take into consideration the perceived quality of life that may change during the ageing process (i.e. QALYs) may also be relevant in this type of assessment and considerably impact LY gains when projected into the future. A more detailed description of these and other issues related to LY weighting are further described in [69].

Finally, an important issue not yet considered in life tables methods that may be of relevance when estimating the benefits for morbidity as well as mortality of air pollution reduction is the role of the increase in morbidity as a result of postponement of death. We emphasize that postponement of death due to reduction in air pollution is the consequence of reductions in a range of acute and chronic pathologies, thus expansion of life expectancy does not necessarily imply more years lived in morbidity at higher ages. As suggested in this monetary evaluation, after death, CB is an important source of societal cost. Understanding the relationship between changes of CB incidence with changes of mortality risk would be of relevance in economical HIA. Further methodological developments are thus needed in this area.

While many open questions remain about the interpretation of long-term public health benefits of air pollution abatement and about the integration of future population and life-time dynamics in the current monetary evaluation, we emphasize that air pollution reductions are expected to lead to gains in life expectancy due to reduction in morbidity and mortality. Thus, the broader discussion of costs and benefits of the ever expanding life expectancy observed in many societies around the world also applies.

7. General conclusions

Air quality, namely levels of PM and NO_2, in the Barcelona metropolitan area is poor, with trends in recent years showing no improvement if not a degradation of the situation. According to research conducted in Spain and elsewhere, and in line with assessments of several international expert panels including the WHO, the current levels of air pollution in Barcelona are a health hazard. This study has shown that important public health benefits could be obtained in terms of morbidity, mortality, and life expectancy if the levels were decreased to WHO guidelines levels developed for protecting public health and adopted by many European countries. Despite a likely underestimation of total benefits, this study showed that the health benefits obtained per year for a reduction of air pollution to levels recommended by the WHO could be:

- **3,500 fewer annual deaths (about 12% of all deaths among people 30 years and older), this representing about 14 months increase of the life expectancy;**
- **1,800 fewer hospitalizations for cardio-respiratory diseases;**
- **5,100 fewer cases of chronic bronchitis symptoms among adults;**
- **31,100 fewer cases of acute bronchitis among children; and**
- **54,000 fewer asthma attacks every year among children and adults.**

The metropolitan area of Barcelona is one of the few remaining urban areas in Europe were EU regulated limit values, less stringent than WHO guidelines, are still exceeded. This evaluation showed that **one third** of the benefits listed above could already be obtained if air pollution was decreased to these current regulatory levels.

While discussions continue about the most appropriate methods to adopt in the economic valuations, this study showed that the estimated economic benefit obtained is expected to be large under various alternative approaches. This study showed that the economic benefits obtained for a reduction of air pollution to levels recommended by the WHO could be 700 to 1,600 Euros per person per year or a total of 3,000 to 6,400 million Euros.

The adverse health impacts and economic costs of air pollution are not distributed equally. Factors like socio-economic status, age and medical predisposition increases the risk of suffering from health effects due to air pollution. Exposure to traffic-related pollution, the main contributor to poor air quality in the Barcelona metropolitan area, is also one of these risk factors. The urban structure in the Barcelona metropolitan area, where people tend to live near very busy streets with particularly high concentrations of traffic-related pollutants suggests a substantial fraction of the health problems being due to traffic. Further evaluation is needed to map these socio-economic distributions because they may provide valuable information for policy makers for rethinking current urban development in the Barcelona metropolitan area.

In the future, as the population grows and the traffic intensifies in the Barcelona metropolitan area, the health impact and economic cost of air pollution for individuals and the society as a whole are likely to increase if actions are not taken rapidly. The benefit of such actions is large, and most probably would be noticeable immediately, and in the long term as air quality improves.

Local authorities in the Barcelona metropolitan area are currently developing a mitigation plan to reduce air quality to the regulated EU levels. This is an important first step for reducing the impact on health of air pollution for the population of the area. However, because a very large percentage of the population is exposed to levels below these limits, identifying and implementing mitigation strategies that ultimately reach the levels proposed by the WHO is critically important, and will produce substantial additional gains for the people of the Barcelona metropolitan area.

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