Estimating the health and economic benefits associated with reducing air pollution in the Barcelona metropolitan area (Spain)

Laura Pérez a,*, Jordi Sunyer a and Nino Künzli a,b

Abstract

Objectives: To estimate the health and economic benefits that would result from two scenarios of improved air quality in 57 municipalities of the metropolitan area of Barcelona.

Methods: We used attributable fractions and life tables to quantify the benefits for selected health outcomes, based on published concentration-response functions and economic unit values. The mean weighted concentration of PM$_{10}$ for the study population was estimated through concentration surface maps developed by the local government.

Results: The annual mean health benefits of reducing the mean PM$_{10}$ exposure estimated for the population in the study area (50 μg/m$^3$) to the annual mean value recommended by the World Health Organization (20 μg/m$^3$) were estimated to be 3,500 fewer deaths (representing an average increase in life expectancy of 14 months), 1,800 fewer hospitalizations for cardio-respiratory diseases, 5,100 fewer cases of asthma attacks among children and adults, and 54,000 fewer asthma attacks among children and adults. The mean total monetary benefits were estimated to be 6,400 million euros per year. Reducing PM$_{10}$ to comply with the current European Union regulatory annual mean level (40 μg/m$^3$) would yield approximately one third of these benefits.

Conclusions: This study shows that reducing air pollution in the metropolitan area of Barcelona would result in substantial health and economic benefits. The benefits are probably underestimated due to the assumptions made in this study. Assessment of the health impact of local air pollution is a useful tool in public health.

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Keywords: Air pollution, Health impact assessment, Preventive medicine, Attributable cases, Monetary evaluation

Introduction

Experimental studies conducted in cellular models, animals and humans, and numerous epidemiological studies have shown that short-term and long-term exposure to current levels of anthropogenic air pollution lead to morbidity and mortality in humans. In the last decade, scientists and public health agencies have translated these research findings into quantities that reflect the burden on health attributable to air pollution in a given region, country, or city. This process is important because it directly informs policy makers and the public about the current situation or the impact of future or past air pollution policies. Regional studies have also been used as tool for prioritizing national regulation and policy development. Given that every society has...
limited resources to allocate, decision makers request that health quantities be transformed into monetary valuations to be compared with mitigation investments. Thus, valuation of health effects is a critical component of health impact assessment (HIA)\(^6\).

Air quality characterized by the inhalable fraction of particulate matter (PM\(_{10}\)), nitrogen dioxide (NO\(_2\)) and other pollutants is poor in the Barcelona metropolitan area, with trends in recent years showing progressive degradation\(^7\). In 2007, when the local government initiated actions to reduce air pollution, questions arose about the potential health and economic benefits of abatement strategies. Air pollution burden for Spain and Barcelona has been partially estimated by different European studies\(^8\)–\(^10\). An assessment of 26 European cities estimated that reducing PM\(_{2.5}\) levels in the city of Barcelona would decrease the numbers of deaths among people aged 30 years and over from 1.5\% (95\% confidence interval [CI]: 0.4\%–3.0\%) to 5.4\% (95\%CI: 1.4\%–10.4\%)\(^9\). In Spain, only one study has incorporated cost into this type of evaluation\(^10\). Comparing year 2000 emission levels to current legislation, this study estimated that air pollution caused morbidity diseases and approximately 22,000 premature deaths. This impact translated into a total cost of 400 to 1,000 euros per year per capita, depending on the method of calculation selected.

This article estimates the health and economic benefits associated with reducing air pollution in the Barcelona metropolitan area from current levels to the European Union (EU) standards and World Health Organization (WHO) targets. Few HIAs have analyzed air pollution burden at the community level, although local analysis might lead to better decision making. This study demonstrates how HIA may support public health policy at a scale that reflects conditions for the community for which policies will be designed or implemented.

**Methods**

This study follows standard methodology to derive the risk attributable to outdoor air pollution\(^10\). The methods require the following information: selection of study area, exposure assessment, health-outcomes, concentration-response functions, scenario of change in exposure considered, and unit monetary values.

**Study area**

We selected as area of study a continuous geographic area constituted by a total of 57 municipalities, including the municipality of Barcelona. For the purpose of our study, we denominated this area “Barcelona metropolitan area”. This study area includes a total population of 3,868,663 inhabitants (year 2004). The municipality level reflects the smallest political unit for which routine health data (i.e. mortality data and hospital admission data) were available. This area was selected for its geographical continuity and potential uniformity in terms of air pollution exposure. Figure 1 presents the 57 municipalities included in the study area with population per 1,000 for 2004.

**Characterizing pollution**

Air pollution is a complex mixture of often highly correlated constituents and pollutants\(^2\). Health impact assessments of air pollution rely on epidemiological studies, using one marker of air quality because it is not appropriate to sum the risk for correlated pollutants\(^11\). For this study, we selected PM\(_{10}\) as marker of air pollution to follow the approach used in other HIAs\(^4,12\) and based on the availability of exposure data for the area of study.

To derive benefits for a specific change in air pollution is necessary to determine the level of exposure of the population before changes occur. We considered the current levels as the point of reference for future changes. The population exposure for PM\(_{10}\) was represented by an average population-weighted concentration derived from a PM\(_{10}\) concentration surface map developed by local authorities. This map estimated 2004 spatial concentration of PM\(_{10}\) through dispersion models that took into account emission sources. Modeled surfaces were validated by comparing concentration levels at fixed monitoring sites with

![Figure 1. Average PM\(_{10}\) concentrations in urbanized areas of the 57 municipalities included in the area of study (population per 1000 for 2004 in parenthesis).](image)
predicted concentrations. This modeled surfaces are used by local authorities to develop air pollution mitigation strategies in the study area. In the context of this study, the population exposure is understood as the average concentration representative of people’s residence. Several approaches are available to determine population exposures depending on the level of detail of the data available. No detailed population distribution was available for our area of study. The estimated population exposure was thus obtained by calculating municipality mean concentrations in urbanized areas based on the government surface map. These means were weighted by the population of each municipality to obtain an average concentration interpreted as the average population exposure since limit values apply to any point of the study area. Attributable fractions were derived with a concentration-response function for the area of study.

Health-outcomes and concentration-response functions

Three main families of health outcomes were evaluated: mortality, morbidity including chronic bronchitis and asthma related symptoms, and health care use represented by hospital admissions for cardiovascular and respiratory diseases. The association between outdoor air pollution and health-outcome frequencies is described with a concentration-response function (CRF). We selected CRF from peer-reviewed literature used in other HIAs. Some of this CRF were expressed for other size fractions of particulate matter (PM), mainly PM$_{2.5}$ or Total Suspended Particles, rather than PM$_{10}$. When needed, conversion factor of 1.06 and 0.6 was used to transform levels of PM$_{2.5}$ or Total Suspended Particles into PM$_{10}$, respectively. Demographic and baseline frequencies of health outcomes were obtained from local health and statistics authorities or, when needed, extrapolated from studies conducted in Europe (Table 1). Characteristics and limitations of the input information are discussed later in the text.

Scenario of change in exposure

We provided risk estimates for two scenarios to reflect the stepwise improvements of air quality expected in the area. The main scenario estimated 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 estimated health benefits for an intermediate step of air pollution abatement, namely reducing current PM$_{10}$ levels to the EU air quality standard. The EU regulation states that PM$_{10}$ levels should not have exceeded a mean annual level of 40 μg/m$^3$ since 2005. This is the year 2010 target of current local policy efforts because the current EU limit has not yet been met in several areas of Catalonia. In the context of this study, the WHO and the EU limit values are interpreted as average population exposure since limit values apply to any point of the territory.

Derivation of attributable number of cases

We expressed results as the number of attributable cases for the change of exposure under consideration. Within this evaluation, attributable cases are interpreted as the number of health events that could be prevented per year if air pollution was reduced. Attributable cases were derived from attributable population fractions applied to number of outcome cases in the population. All calculations were conducted at the aggregated level of the study area. Attributable fractions were derived with the standard formula $\text{AF}_{\text{pop}} = [p_0 \cdot \text{RR}]/[p_0 \cdot \text{RR} - 1 + 1]$, where $p_0$ represents the fraction of the population exposed to air pollution and assumed as one, and RR represents the relative risk (RR) of the CRF for the change in PM$_{10}$ exposure considered. RR is

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Health outcomes (number or percentage) and concentration-response functions in the area of study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outcome</td>
<td>Age</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Mortality</td>
<td></td>
</tr>
<tr>
<td>Infant death (ICD10 A00-R99)</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Short-term effects all causes (ICD10 A00-R99)</td>
<td>All</td>
</tr>
<tr>
<td>Long-term effects all causes (ICD10 A00-R99)</td>
<td>≥ 30</td>
</tr>
<tr>
<td>Hospital admissions</td>
<td></td>
</tr>
<tr>
<td>Hospital admission for respiratory diseases (ICD9 460-519)</td>
<td>All</td>
</tr>
<tr>
<td>Morbidity</td>
<td></td>
</tr>
<tr>
<td>Chronic diseases</td>
<td>≥ 25</td>
</tr>
<tr>
<td>Asthma related symptoms</td>
<td></td>
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</tbody>
</table>

CMBDAH: Registre del Conjunt Mínim Bàsic de Dades de l’Alta Hospitalària; SCARPOL: Swiss Surveillance Program of Childhood Allergy and Respiratory Symptoms; ASHMOG: Adventist Health and Smog; ECHRS: European Community Respiratory Health Survey; SARI: Estudi sobre Salut Respiratori a la Infancia.

a Refers to study in which derivation of pool estimated was undertaken.
derived as \( RR = \exp(\beta \Delta C) \) with \( \beta \) the slope of the CRF expressed for 1 \( \mu g/m^3 \) and \( \Delta C \) the change in exposure considered in \( \mu g/m^3 \). The statistical models used to derive CRFs 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, we corrected OR with a standard formula 18.

**Derivation of years lost**

The concept of attributable or preventable death is conceptually flawed as death is ultimately not preventable but can only be postponed. Those exposed to lower pollution would in fact have, in average, a longer life expectancy due to reduction in death rates. We estimated average increase in life expectancy for our study population using standard life table methods 19.

**Monetary valuation of health benefits**

Economists in different settings have attempted to develop alternative measures of values for benefits arising from clean air 20. Ideally these measures 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 20. In this evaluation, the value to attach to a reduction of the risk of death and other end points were based on the Willingness-To-Pay (WTP) approach. Unit monetary values based on WTP are derived from market choices that reduce risk to health or life indirectly 20. We used same monetary values as those based on alternative CRFs 1. Reference for alternative CRFs: 1Pope et al. (2002) 35; 2Jerrett et al. (2005) 30; 3WHO (2004) 15; 4Medina et al. (2005) 12; 5Le Tertre et al. (2002) 17; 6Abbey et al. (1995) 22; 7Dockery et al. (1989) 23; 8Dusseldorp et al. (1995) 24; 9Roemer et al. (1993) 25; 10CAFE (2005) 10.

**Expression of uncertainty**

The various steps described above come with a range of assumptions and uncertainties, which differ for the different outcomes. To reflect these uncertainties results are presented with a point estimate as well as an upper and lower bound given by the 95%CI of the CRF. For other uncertainties and assumptions, a series of sensitivity analyses were conducted to assess the differences between our mean results and results under alternative assumptions. Figure 2 summarizes the percent change that would have applied to our central benefits of the different health point studied if alternative assumptions had been selected. Alternative assumptions were grouped into four: use of the upper and lower bound of the 95%CI of CRF; use of other CRFs; assuming some error in the baseline frequencies used; and use of alternative monetary values or approach.

**Results**

Based on the 2004 concentration surface maps, PM\(_{10}\) mean average concentrations for the study area was 43 \( \mu g/m^3 \), ranging

![Figure 2](https://example.com/figure2.png)

**Figure 2.** Sensitivity of results expressed as percent change from the central point estimate of the benefits obtained for the different end-points studied. (1) Use of upper and lower bound of the 95% of CRF; (2) use of central estimate of alternative CRFs; (3) assuming some error in the baseline frequencies used; (4) use different monetary valuation range and approach.


between 35 and 56 \( \mu g/m^3 \) depending on the municipality. The highest mean concentrations were observed for municipalities with the highest number of inhabitants (i.e. municipality of Barcelona) (Fig. 1). For the study area, we estimated a PM\(_{10}\) average exposure concentration of 50 \( \mu g/m^3 \) representative for a population of approximately four million inhabitants (all ages).

Following the traditional approach of reporting the burden of disease by attributable deaths, we estimated that approximately 3,500 (95%CI: 2,200–4,800) fewer deaths due to short-term exposure could be reduced if outdoor air pollution was reduced to levels recommended by the WHO (Table 2). We estimated that this translates to an average 14 months increase in life expectancy (95%CI: 6–22 months). In addition, we estimated that there could be nearly 1,800 (95%CI: 1,200–2,300) fewer hospital admissions for cardio-respiratory diseases; 5,100 (95%CI: 550–8,500) fewer cases of chronic diseases in adults; 31,100 (95%CI: 17,500–40,500) fewer cases of acute bronchitis in children; and approximately 54,000 (95%CI: 27,400–75,700) fewer asthma attacks in adults and children if exposure to air pollution was reduced to the levels recommended by the WHO. One third of the benefits of the WHO scenario could already be obtained if air pollution was decreased to EU regulatory levels. Because the associations between air pollution and the health outcomes considered in this study are linear, these latter benefits can also be interpreted as the intermediate benefits that would be obtained per each decrease of 10 \( \mu g/m^3 \) of ambient concentrations in the area of study.

Results of the monetary valuation (Table 3) showed that, the estimated total aggregated economical benefits were 6,400 million Euros (95%CI: 3,500 to 9,000 million Euros) translating to per capita benefits of 1,600 euros (95%CI: 870–2,300) per year for the WHO scenario. Total economical benefits would amount to 2,300 million euros (95%CI: 1,200–3,300) per year if air pollution was decreased to EU regulatory levels. More than 80% of the

### Table 2

Expected health benefits per year for an annual reduction of PM\(_{10}\) in the area of study

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Age(^a)</th>
<th>Health benefits (95%CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Decrease to annual mean concentration of 20 ( \mu g/m^3 )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Attributable number of cases</td>
</tr>
<tr>
<td>Mortality</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infant death</td>
<td>All causes</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Death due to short-term exposure (acute)</td>
<td>All causes</td>
<td>≥ 30</td>
</tr>
<tr>
<td>Total death (long-term exposure; includes above acute effect)</td>
<td>All causes</td>
<td>≥ 30</td>
</tr>
<tr>
<td>Hospital admissions</td>
<td>Respiratory causes</td>
<td>All</td>
</tr>
<tr>
<td>Cardiovascular causes</td>
<td>All</td>
<td>620 (310–930)</td>
</tr>
<tr>
<td>Morbidity</td>
<td>Chronic bronchitis adults</td>
<td>≥ 25</td>
</tr>
<tr>
<td>Acute bronchitis children</td>
<td>&lt; 15</td>
<td>31,100 (17,500–40,500)</td>
</tr>
<tr>
<td>Asthma related symptoms</td>
<td>Adults</td>
<td>≥ 15</td>
</tr>
<tr>
<td>Asthma attacks children</td>
<td>&lt; 15</td>
<td>12,400 (6,400–15,200)</td>
</tr>
</tbody>
</table>

\(^a\) Applies to population with age defined by concentration-response function.

### Table 3

Monetized benefits per year for an annual reduction of PM\(_{10}\) in the area of study

<table>
<thead>
<tr>
<th>Health outcomes</th>
<th>Unit value in Euros(^a)</th>
<th>PM(_{10}) annual mean reduction to 20 ( \mu g/m^3 )</th>
<th>% total benefits (95%CI)</th>
<th>PM(_{10}) annual mean reduction to 40 ( \mu g/m^3 )</th>
<th>% total benefits (95%CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mortality</td>
<td>Attributable deaths(^b)</td>
<td>Median: €1,020,000/death</td>
<td>5,400 (3,400–7,400)</td>
<td>84% (82%–97%)</td>
<td>1,900 (1200–2700)</td>
</tr>
<tr>
<td>Morbidity</td>
<td>Hospital admissions</td>
<td>€2,100/admission</td>
<td>3.7 (2.0–5.4)</td>
<td>&lt; 1%</td>
<td>1.3 (0.7–1.8)</td>
</tr>
<tr>
<td>Chronic bronchitis (adults)(^b)</td>
<td>Median: €125,000/case</td>
<td>970 (100–1,600)</td>
<td>15% (3%–18%)</td>
<td>360 (40–700)</td>
<td>16% (3%–20%)</td>
</tr>
<tr>
<td>Total asthma symptoms</td>
<td>€39/day</td>
<td>2.1 (1.1–3.0)</td>
<td>&lt; 1%</td>
<td>0.7 (0.4–11)</td>
<td>&lt; 1%</td>
</tr>
<tr>
<td>Total monetized benefits</td>
<td>€6,400 (3,500–9,000)</td>
<td>100%</td>
<td>2,300 (1,200–3,300)</td>
<td>100%</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) Transformed to 2006 price-year.

\(^b\) Use of mid value estimates to monetize benefits.
economical benefits were due to the reduction of long-term attributable deaths.

Discussion

This assessment indicates that health and economical benefits would be substantial if air pollution was reduced in the Barcelona metropolitan area. HIA provides a framework to evaluate the relevance of community-based policy decisions to public health. However, assumptions and uncertainty concerning methods must be considered when interpreting results.

In this study, we made several assumptions that most likely have underestimated the benefits of reducing air pollution. First, we selected PM10 as a marker of air pollution. Recent European assessments have used smaller fractions of PM, specifically PM2.5. Although variations may occur depending on location and hour of the day, PM2.5 and PM10 in the Barcelona metropolitan area are relatively highly correlated. Thus, results of a PM2.5-based assessment are expected to be similar. However, we ignored effects and interactions with other pollutants that may have independent effects. In particular, effects of ozone (O3) were not included. A recent report of the US Academy of Sciences recommended the use of acute effects of ambient O3 in risk assessment. Also, recent research indicates that pollutants which occur in very high concentrations close to busy streets, e.g., the ultrafine fraction of PM, may have a particularly detrimental effect on health. PM10 does not capture these traffic-related exposure differences within Barcelona, thus our estimation may not fully reflect these effects. The future availability of concentration surfaces for PM2.5 or even the finer fraction of PM such as ultrafine would be an important contribution to this health impact assessment. Second, air pollution has adverse health effects (i.e., self-medication, restricted activity days, cardiovascular diseases, etc) not included in this assessment due to incomplete data. Third, we have assumed that air pollution is a risk factor for acute asthma attacks only. While not conclusive, several studies indicate that air pollution, in particular traffic emissions, may lead to onset of asthma in children. Therefore, we may have underestimated the public health benefits of reducing both acute and chronic effects.

Fourth, recent studies indicate that the CRF for long-term effects of air pollution on mortality, which we used in this study, may be an underestimation. Fifth, we estimated annual results assuming an hypothetical scenario where PM10 concentrations would have decreased during one year only. Sustained reduction of air pollution would result in larger cumulative benefits for the population. In addition to these assumptions, we used the current EU standard and WHO target as reference levels in our assessment. The EU standard, based on older evidence and confirmed by parliament in 2007, is high compared to standards adopted by several European countries, the United States, and the new WHO target. Although target values are regulatory instruments with compliance requirements that differ between countries, the revised values adopted by these countries reflect a more stringent vision of protecting public health. Adopting this more stringent WHO target would yield benefits three times larger than those achieved by reducing air pollution to the current EU standard. For the purpose of this study, the WHO and EU ambient limit values are interpreted as target average population exposure. This is consistent with the compliance approach of local authorities that assumes that any location in the area of study area must reach the prevalence of asthma based on 10,821 children aged between 10 and 44 years. The underlying number of asthmatics was obtained from the cross-sectional Barcelona SARI study (Estudio sobre la Salud Respiratoria en la Infancia), that derived the prevalence of asthma based on 10,821 children aged between 7 and 8 years recruited from primary schools in the cities of Barcelona and Sabadell. Health monitoring projects could substantially enhance the ability to estimate public health risks of various exposures. Finally, WTP approaches rely on respondents’ ability to answer when estimating how much they are willing to pay for small changes of risks. Analysis showed that uncertainty around these unit values is large, averaging 50%. Taken together, these alternative assumptions show that presenting a range of uncertainty around the mean estimate based only on the 95%CI of the CRF may be too simplistic. However, studies using probabilistic models have also shown that uncertainties associated with the exposure-response coefficient, and plausibility of the cardio-pulmonary mortality are greater than when compared with other uncertainties. Considering current knowledge, our evaluation presents a general estimate of benefits.

As in other HIAs, the overall burden attributed to air pollution was heavily driven by mortality due to long-term exposure, thus this outcome requires further discussion. Most of these
studies express results in terms of attributable deaths, a common approach used for other risk factors. However, expressing results in terms of life expectancy rather than attributable deaths is increasingly favoured. Our study expresses results using both approaches. This change reflects the fact that the concept of attributable deaths, and in particular the often interchangeably used term preventable death, is misleading, because reducing pollution postpones rather than prevents death. As a cohort ages, and the benefits of reducing air pollution are realized, the number of attributable deaths will not remain constant, and gains will sum to zero when all members of the cohort are dead. Long-term air pollution benefits are thus more appropriately expressed in terms of life years gained or life expectancy because life years accumulate independently of attributable deaths (Fig. 3), developed following methods in Miller and Hurley report, presents the evolution under WHO scenario.

The use of life years has considerable impact on economic valuation. Using a published value of life year (VOLY), we estimated that, without discounting, the total annual monetary benefits would be approximately 50% less than benefits obtained using attributable death and associated monetary values. Similar differences have been obtained in other evaluations. While expressing results in terms of life years gained may be more accurate, communicating these results to lay people is more complex than dealing with attributable deaths. In addition, many questions remain regarding the interpretation of long-term public health benefits of air pollution abatement strategies, including the integration of future populations and life-time dynamics in calculations, and the appropriateness of discounting and weighting.

In conclusion, the results of this study indicate that the health and economic benefits of reducing air pollution in the Barcelona metropolitan area may be substantial. These benefits could only be estimated in crude terms, due to a range of inherent uncertainties and other methodological limitations. Despite these limitations, local air pollution HIAs are useful tools to translate research results into community-based evidence to protect public health.

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