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**Health impact assessment of a reduction in ambient air PM<sub>2.5</sub> level in Spain**

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## ABSTRACT

**Background:** Health effects related to exposure to high levels of air pollutants have been well described, and many recent epidemiological studies have also consistently shown positive associations between exposure to air pollutants at low concentrations and adverse health outcomes, especially for PM<sub>2.5</sub>.

**Objective:** To estimate the number of avoidable deaths associated with reducing PM<sub>2.5</sub> levels in Spain.

**Materials and methods:** For exposure assessment, we used the U.S. Environmental Protection Agency's (EPA) Community Multi-scale Air Quality model to simulate air pollution levels with a spatial resolution of 18x18 Km<sup>2</sup>. Two different scenarios were compared: a 2004 baseline scenario based on the Spain's National Emission Inventory, and a 2011 projected scenario in which a reduction in PM<sub>2.5</sub> was estimated based on the benefits that might be attained if specific air quality policies were implemented. Los datos de contaminación de aire fueron estimados para una rejilla de 18 x 18 Km<sup>2</sup> para toda la Península Ibérica, Islas Baleares, Ceuta y Melilla. Accordingly, for these strata, we calculated crude mortality rates corresponding to all causes (ICD-10: A00-Y98) in the age groups of older than 30 years old and from 25 to 74 years old, and population figures in 2004 corresponding to the same previously mentioned age-groups, according to the selected Concentration-Response Functions (Pope et al., 2002; Laden et al., 2006). Health impact was assessed using the BenMap software.

**Results:** Air quality improvement was estimated as an average annual reduction of 0.7 µg/m<sup>3</sup> in PM<sub>2.5</sub> levels. For the age group older than 30, the HIA analysis in the long-term estimated 1,718 avoidable deaths for all causes by year (6 deaths per 100 000 inhabitants). For the age group of 25-74 years, 1,447 avoidable deaths (5 deaths per 100 000 inhabitants) could be prevented annually.

**Conclusions:** The results showed the potential benefits in general mortality that could be expected if pollution control policies were successfully implemented by 2011. BenMAP could be used as a tool for estimating the health impacts associated with changes in air pollution in Spain under specific adaptations.

**Key words (3-6):** environmental pollution, particulate matter, mortality, Risk Benefit Assessment, software tool

## 1. INTRODUCTION

There is a general scientific consensus that air pollution constitutes an important public health concern (Pope and Dockery, 2006). Entre los contaminantes del aire, destaca the Particulate Matter (PM), and especially those particles with less than 2.5 micrometers in diameter (PM<sub>2.5</sub>, also known as fine particles), dado que parecen estar relacionadas con los efectos más graves en salud, including lung cancer and other cardiopulmonary mortality (Peters et al., 2001; Pope et al., 2002). En EEUU existe una larga tradición en el estudio de los efectos en la salud a largo plazo de las PM<sub>2.5</sub>, gracias a la aportación de diversos estudios de cohortes (Dockery et al., 1993; Pope et al., 2002). En Europa, el interés por este contaminante es cada vez mayor, dado que los niveles de PM<sub>2.5</sub> están aumentando notablemente en las últimas décadas, sobre todo en áreas urbanas (Perez et al., 2009). Este hecho y la medición reciente de este contaminante en grandes urbes europeas han permitido la realización de diversos estudios epidemiológicos (Brunekreef et al., 2009; Naess et al., 2007), cuyos resultados preliminares están en la línea de los estudios americanos.

El conocimiento generado por los estudios epidemiológicos ha llevado a la adopción de distintas medidas de control de la contaminación atmosférica aimed to reduced its health effects. However, most of the public health interventions or policy changes on this matter cannot be evaluated directly. In this context, health impact assessment methodology (WHO, 2000) is a valuable tool, as it relies on available pollutant exposure-disease effect estimates and can be used to estimate the expected reduction in the burden of disease attributable to various scenarios of improvements in air quality (Krzyzanowski et al., 2002; Martuzzi et al., 2003). Up to now, at the European level, HIA has allowed to quantify the health effects of reducing urban air pollution, mostly by reducing cardiovascular or respiratory mortality and morbidity (Ballester et al., 2008; Boldo et al., 2006; Clancy et al., 2002; Medina et al., 2004; Wang et al., 2009)

In Spain the research project Air Pollution Risk Assessment System (SERCA) was set up to perform HIA in this issue for the whole country, thanks to a multidisciplinary approach combining researchers with expertise in detailed air pollution estimation and public health professionals. This project will provide for the first time national estimates of deaths that could be avoided in Spain if air pollution control measures were implemented.

The extensive use of HIA on air pollution area has induced some researchers to develop specific software tools to help to estimate the health impact related to changes in air quality. One of the best known is the Environmental Benefits Mapping and Analysis Program (BenMAP) (Abt Associates Inc, 2005), developed by the U.S. EPA to perform customized HIA and benefit-cost analyses of air quality regulations (Davidson et al., 2007; Fann et al., 2009). This software integrates a HIA calculator and a GIS, and provides as outputs global estimates of impact (i.e. number of avoidable deaths for the study area) combined with the geographical distribution of the selected impact indicator para distintos escenarios simulados de cambio en la calidad del aire. However, this tool has been rarely used outside EEUU (Bae and Park, 2009; Tagaris et al., 2009)

The aim of this paper is to perform a preliminary assessment of the number of total avoidable deaths attributable to a reduction in PM<sub>2.5</sub> concentrations in Spain within the SERCA project. For this purpose we compared a 2004 baseline scenario based on the Spain's National Emission Inventory, and a 2011 control scenario with a theoretical reduction in PM<sub>2.5</sub> exposure based on the implementation of planned air quality policies. BenMAP (version 4.0.27) was used as HIA calculating tool. We report the advantages and difficulties found in the customisation of this software for its use in our context

## **2. MATERIALS AND METHODS**

### **2.1. Air pollution scenarios: 2004-2011.**

For this health impact assessment we defined a baseline scenario, which corresponded to year 2004, and a control scenario, which would simulate pollution distribution in year 2011 had some air quality control measures planned at 2004 been successful.

The baseline scenario is derived from the Spain's National Emission Inventory (year 2004). The control scenario (year 2011) is taken from the baseline scenario defined for Spain according to the Spain's Emission Projections (SEP) methodology (Lumbreras et al., 2008). and assumes significantly decreased emissions of PM<sub>2.5</sub> precursors (e.g. a 10.7% reduction of primary PM<sub>2.5</sub>) due to technological measures in the road transport sector, industry, agriculture and power generation (further details about the control scenario and emission levels can be found in the preliminary analysis carried out in (Orozco et al., 2009).

In both scenarios, emissions were initially processed through the Sparse Matrix Operator Kernel Emissions (SMOKE) modelling system (Borge et al., 2008), and afterwards were applied the EPA CMAQ 4.6 model (Byun and Ching, 1999; Byun and Schere, 2006) to simulate PM<sub>2.5</sub> (µg/m<sup>3</sup>) concentrations levels for the whole Iberian peninsula, along with Balearic Islands, Ceuta and Melilla, using a grid with a spatial resolution of 18x18 Km<sup>2</sup>(4032 cells). Canary Islands were not included for the estimations. Air pollution changes in each cell were calculated in the HIA tool (BenMAP) by subtracting air pollution levels resulting from CMAQ (control - baseline).

### **2.2. Population at risk and mortality rates for the baseline scenario.**

For each town in Spain (8,109 municipal cores), the Spanish National Statistics Institute provided population data and number of deaths corresponding to all causes mortality, including external causes (International Classification of Diseases, 10th revision [ICD-10], code A00-Y98) broken down by 5 years age-group for 2004-2006. This period was selected, in spite of non corresponding to the air-pollution midway point (2004), to avoid the effects on mortality related with the heat wave that affected Spain in 2003 (Martinez et al., 2004).

Each municipality was assigned the geographical coordinates corresponding to its centroid, and an overlapping grid similar to that used for the air quality models was then applied using SIG software to calculate number of deaths and population by cell. In those cells including more than one municipal centroid, data on mortality and population were aggregated to obtain a unique value by grid cell. Afterwards we calculated average crude mortality rates as well as average population figures broken down by 5 years age-group by cell across the three years to provide more stable estimates.

### **2.3. Selection of the Concentration-Response Functions.**

According to guidance from scientific panels (National Research Council, 2002; US EPA, 2001), the most appropriate health effect estimates for our purpose are those obtained from cohort epidemiological studies designed to assess the impact of long-term exposure to PM<sub>2.5</sub>. Thus we decided to use CRFs from the cohorts that satisfied the following quality criteria: (1) to use PM<sub>2.5</sub> concentrations as primary exposure pollutant, (2) to cover the broadest potentially exposed population, (3) to have an appropriate model specification (e.g. controlling for confounding pollutants), (4) to have been published in major peer reviewed scientific journals.

We identified two studies that fulfilled all the criteria: the estimations for the American Cancer Society cohort (Pope et al., 2002), and the reanalysis of the Harvard Six Cities cohort (Laden et al., 2006). Table 1 shows the main features of the epidemiological studies selected for our HIA analysis.

### **2.4. Estimation of the health impact using BenMAP software.**

We used the U.S. EPA's BenMAP software as a HIA tool (<http://www.epa.gov/air/benmap/>) to estimate crude figures of avoidable deaths attributable to the air quality changes. The methodology implemented in this tool is described in detail elsewhere (Fann et al., 2009). BenMap es además compatible con the Community Multi-scale Air Quality (CMAQ) models of the U.S. EPA, lo que facilita enormemente la incorporación de los escenarios de exposición a la contaminación atmosférica.

For each grid cell within Spanish boundaries, we introduced in the software the data for the baseline scenario (average population figures, mortality rates broken down by 5 years age-group, and PM<sub>2.5</sub> estimated levels in 2004) and control scenario (PM<sub>2.5</sub> estimated levels by cell in 2011). For each selected CRFs, BenMAP uses the mean estimate of its regression coefficient ( $\beta$ ) and its standard error to calculate a distribution of point estimates at each grid cell of the number of avoided deaths associated with PM<sub>2.5</sub> changes between the two considered scenarios, limiting the analyses to age groups from 30 to 99 years old for Pope CRF (Pope et al., 2002), and to 25-74 age groups for Laden CRF (Laden et al., 2006). For each grid cell we selected the median, and the 5<sup>th</sup> and 95<sup>th</sup> percentiles of this distribution to provide a range of the uncertainty for HIA results. National figures of avoidable deaths were obtained by adding up all cell estimates.

### 3. RESULTS

According with our estimations, the control scenario proposed would implied a generalized improvement of PM<sub>2.5</sub> annual mean concentration values (up to 4 µg/m<sup>3</sup>), though national average air quality change (PM<sub>2.5</sub> average annual concentration) between 2004 and 2011 estimated by the CMAQ would be moderated (0.7 µg/m<sup>3</sup>). Figure 1 represents the geographical variability of air pollution changes between control and baseline PM<sub>2.5</sub> scenarios. The highest reduction in PM<sub>2.5</sub> levels is observed around major Spanish cities such as Madrid, Barcelona or Valencia, which are the largest primary producers of PM<sub>2.5</sub> concentrations due to their high traffic density. Also noteworthy are the reductions in the Mediterranean area and East Andalusia provinces, where changes might be more related to local decreases of emissions on particular industrial sectors.

Table 2 summarises the long-term HIA findings in terms of number of absolute attributable deaths (at the 50<sup>th</sup>, and in the range of the 5<sup>th</sup>-95<sup>th</sup> percentiles) and crude rates per 100,000 inhabitants that could be potentially prevented for the scenario of PM<sub>2.5</sub> reduction in Spain. According to the risk estimated by Pope (Pope et al., 2002), our analysis found a mean of 1,718 avoidable deaths (range from 673 to 2,760) for the population older than 30 years (27,327,894 in 2004), if long-term exposure to outdoor concentrations of PM<sub>2.5</sub> were reduced as projected in the future scenario. This figure corresponds to a crude rate of 6 deaths per 100 000 inhabitants, and would mean around 0.5% of the total number of deaths of this population. Similar results were obtained according to the risk calculated by Laden (Laden et al., 2006) , with a mean of 1,446 avoidable deaths (ranging from 780 to 2,108) for population aged between 25 and 74 years (27,581,510 in 2004) and a crude rate of 5 avoidable deaths per 100 000 inhabitants.. It would represent around 1.25% of the total number of deaths within this age range.

Figure 2 represents the geographical distribution of the absolute number of avoidable deaths and the crude rate of avoidable deaths per 100.000 inhabitants estimated using Pope and Laden CRFs. Major health benefits in terms of absolute number of avoidable deaths (Figures a.1, b.1) would be obtained with both CRFs in the most densely populated cities of Spain like Madrid, Barcelona and Seville and its peripheral areas, and there are very small differences between the two estimations. However, the geographical distribution of the crude mortality rates (Figures a.2, b.2) indicates that the greatest health benefits in relative terms would occur in areas of Andalusia and the Mediterranean area. Comparing the health impact between the two age groups, we observed a greater impact in the group older than 30 years (Pope et al., 2002) as it includes the elderly, unlike Laden's approach (Laden et al., 2006), which only includes people aged 25 to 74 years.

### 4. DISCUSION AND CONCLUSIONS

Este trabajo presenta la primera estimación en España de ámbito nacional del impacto de la mortalidad de cambios en los niveles de PM<sub>2.5</sub> levels. Using CMAQ models for PM<sub>2.5</sub> exposure assessment and BenMAP as



HIA tool, we estimated that a feasible reduction of PM<sub>2.5</sub> levels between 2011 and 2004 (according to national emission projections) would approximately avoid 1,447 deaths annually in Spain in the age group from 25 to 74 years old (according to Laden et al., 2006) or 1,718 deaths in older than 30 years (according to Pope et al., 2002), had the population remained stable. Most of these deaths would correspond to the main urban areas.

Our global results are consistent with previous HIA studies performed in Europe and in Spain (Alonso et al., 2005; Ballester et al., 2008; Boldo et al., 2006; Medina et al., 2004; Perez et al., 2009). Todos estos estudios mostraron que la reducción de los niveles de contaminantes atmosféricos en grandes ciudades, PM<sub>2.5</sub> concentrations in particular, could result in a substantial decrease in the number of premature deaths, and in a considerable increase in life expectancy. The analysis conducted in this paper attempts to improve those first approaches, modelling PM<sub>2.5</sub> levels for the whole country and simulating future scenarios for the levels of this pollutant based on air quality polices. Hasta el momento, se desconoce la existencia de otro estudio en el marco europeo que presente una HIA para PM<sub>2.5</sub> realizada a nivel nacional.

The interpretation of these results should be done with caution, and its limitations should be clearly stated. The validity of our HIA estimates depends fundamentally on three points: la calidad de los datos de población y de salud, la calidad de los datos de exposición y las estimaciones de riesgo utilizadas. Firstly, in Spain, the population at risk and the baseline incidence rates come from reliable data sources, as they have been provided by the Spanish National Statistics Institute

Regarding the calidad de los datos de exposición in our analysis, the BenMap is suited to the outputs of a mesoscale Eulerian chemical-transport model such as CMAQ, and therefore for the assessment of alternative emission scenarios in the SERCA project scope. The control scenario in this contribution implies a significant reduction of primary PM<sub>2.5</sub> and other PM precursors in most of the main sectors. From this estimate of future emissions and the corresponding meteorology, 1-h concentration values are obtained for the whole year. In practice, an annual average is considered to be sufficient to represent long-term average concentrations of ambient PM (WHO, 2003). Although apparently our results show a discrete reduction in PM<sub>2.5</sub> concentrations (less than 1 µg/m<sup>3</sup> as an average), it should be considered that they reflect the air quality improvement expectable from the implementation of a series of policies, more than a prescribed reduction, quite unfeasible in practice. Besides sensible emission reduction scenarios of primary precursors of PM<sub>2.5</sub> concentrations, the air quality modelling system takes into account atmospheric dynamics and chemical reactions in the atmosphere as accurately as possible for a given spatial resolution. In this case, the system was found useful to assess the number of avoided deaths using a model grid of 18x18 Km<sup>2</sup> resolution. More specific results are expected in the framework of the SERCA project from the application of the BenMAP software with increased model resolution (e.g. 3x3 km<sup>2</sup> resolution or even higher for particular locations).

El tercer punto clave de la HIA es la selección del estimador o estimadores de riesgo relativo o CRFs, que deben ser considerados la mejor estimación disponible en la literatura para representative health outcomes related con la exposición estudiada. For this study, we used two CRFs related to PM<sub>2.5</sub> exposure (Laden et al., 2006; Pope et al., 2002). En este sentido, debe comentarse que las dificultades de obtener estimadores para

exposiciones ambientales como la que nos ocupa hace que las CRFs existentes, a pesar de ser las mejores que existen en la literatura, sean excesivamente generales, e incluyan por tanto estimadores de riesgo que son comunes para ambos sexos y sin diferenciar grupos de edad a pesar de que probablemente los efectos no son los mismos si se consideran estos subgrupos. Asimismo, it is important to state that we could not compare the findings using Pope' and Laden's CRFs due to major differences in both studies showed in Table 1 (eg. the age groups in the target population were different). Se seleccionaron estudios americanos porque en Europa los estudios de cohorte se han iniciado recientemente, dado que no se medía la exposición a PM<sub>2.5</sub> en la mayor parte de las ciudades europeas. No obstante, preliminary findings from European cohort studies suggest that traffic-related air pollution tiene un efecto en la mortalidad a largo plazo (Brunekreef et al., 2009; Hoek et al., 2001), and report higher coefficients than Pope's study. Then, in the absence of robust European's CRFs for long-term exposure to PM<sub>2.5</sub>, the transferability of U.S. CRFs to the European countries seemed appropriate (SCHER-Scientific Committee on Health and Environmental Risks, 2005). Up to now, in the Spanish context, only few cities routinely measure PM<sub>2.5</sub> concentrations, and epidemiological studies addressing the health effects of air pollutants are focused in the short-term effects of this pollutant using the time series approach (Diaz et al., 2001; Jimenez et al., 2009; Linares and Diaz, 2010).

En relación a la herramienta utilizada para la HIA, debe señalarse que el BenMAP is designed by the EPA and mainly adapted to the available data in the USA. This software can help to perform quick HIA in USA context, as its pre-loaded information includes population, geographical boundaries, and CRFs from USA studies. Sin embargo, el uso de este software en otro contexto distinto del estadounidense to estimate health impacts of air pollution requires training courses, and any further custom analysis require further specific adaptations to input data. En nuestro caso, the customization of BenMap for Spain required no solo a previous adaptation of the data in order to fit the requirements of the program, sino que también we needed support from the developers of the program in this task. However, futures HIA for the same geographical area can take advantage of this previous work. According to the HIA findings obtained in this analysis, BenMAP could be a suitable tool to support future HIA reports in the Spanish framework and therefore in other European countries.

In conclusion, the HIA findings showed the potential benefits in mortality that could be expected if pollution control policies were successfully implemented. Our study constitutes the first attempt to carry out a national HIA of air pollution in Spain. In the future, it would be necessary to put these results into perspective by considering the combined uncertainty of emission projections and the current air quality modelling system to prevent the health effects of this important pollutant in the context of climate change in our country.

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