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MADRID'S PLAN A HEALTH IMPACT ASSESSMENT

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Abstract: Alleviating negative health effects is the main driver of environmental legislation and air quality strategies, including the Air Quality and Climate Change Plan for the city of Madrid (Plan A). We investigate the health impact of the implementation of Plan A related to the most relevant pollutants (NO_2, $PM_{2.5}$, O_3). Two annual simulations were performed to depict air quality after (2020; control scenario) and before (2012; baseline scenario) the implementation of the Plan using identical model inputs except for emission datasets, which reflect the expected effect of the 30 abatement measures included in Plan A. Emissions from a very detailed urban emission inventory were processed by SMOKE 3.6.5 to produce chemically speciated and spatio-termporally resolved emissions (1 km^2 horizontal resolution, 30 vertical levels, 1 hour). Meteorological fields were provided by WRF-ARW 3.7.1 (including the BEP parameterization) while ambient air pollution levels were simulated using CMAQ 5.0.2.
Population and daily-mortality data stratified by age and sex for the health impact assessment (HIA) were taken from the Madrid City Council official census and projections for each of the 21 districts in the city. Health endpoints to assess the impact of Plan A were chosen according to the scientific criteria defined within the ICARUS project, following the recommendations of the HRAPIE and REVIHAAP WHO projects. Relevant concentration-response functions were applied to the concentration changes predicted from the comparison of the baseline and control scenarios to assess variations on all non-accidental mortality causes (ICD-10: A00-R99) at district level.
Our results suggest that the full implementation of Plan A would reduce $PM_{2.5}$ and NO_2 annual concentrations by 0.6 $\mu g\ m^{-3}$ and 4.0 $\mu g\ m^{-3}$, respectively and increment O_3 by 1.0 $\mu g\ m^{-3}$ as an average citywide. The annual number of all-cause deaths from long-term exposure (95% CI) that could be postponed in the adult population was 88 (57–117) for $PM_{2.5}$ and 519 (295–750) for NO_2. We found that the highest benefits concentrate in the city centre and that positive impacts far exceeded the adverse mortality effects expected from the increase in O_3.

Key words: *Health impact assessment, urban air quality plan, emission abatement strategies, mortality, ICARUS*

INTRODUCTION

Despite recent emission abatement efforts, pollutant concentrations in many urban areas in Europe are still above the legal and recommended limits that are set to protect the citizens' health. While the burden of disease from ambient air pollution in Europe has been related to $PM_{2.5}$ and O_3 (Lelieveld et al., 2019), Madrid has traditionally presented high NO_2 levels that have driven the air quality polices in the city (Borge et al., 2014). In this context, the Madrid City Council launched the Air Quality and Climate Change Plan for the city of Madrid (Plan A), a local strategy approved by the previous government in 2017 (MCC, 2017) and currently under revision.

The aim of this study was to conduct a quantitative health impact assessment (HIA) to evaluate the health impact of Plan A in Madrid in 2020, the temporal horizon of the Plan, as a part of the European H2020 project ICARUS (ICARUS, 2016). The main purpose was to assess the positive health impacts that could be derived from the full implementation of Plan A measures, something that could provide relevant information for future plans. In addition to inform policy makers, HIA like this can help increasing awareness about air pollution and improving the perception of restrictive measures by the population.

METHODOLOGY

General approach

Standardised HIA methods (Boldo et al., 2011; Borge et al., 2019) were used to assess long-term, mortality variations associated to expected changes on ambient air concentrations of the most relevant pollutants ($PM_{2.5}$, NO_2 and O_3), according to equation (1):

$$\Delta Y = Y_0 \left(1 - e^{-\beta \Delta x}\right) P \quad (1)$$

Where:

- ΔY is the change in the mortality between a future scenario and the current situation (refernce scenario), 2020 and 2012, respectively
- Y_0 is the mortality rate at the reference scenario (for each specific health endpoint and age group according to applied concentration-response functions, CRF)
- β is the coefficient of the CRF for an increase in air pollution concentrations of 1 $\mu g\ m^{-3}$
- Δx is the change in the pollutant concentration between the baseline (2012) and projected scenario (2020) ($\mu g\ m^{-3}$)
- P is the projected population for year 2020.

Air quality modelling system and scenarios

The expected impact of the implementation of Plan A was simulated through an Eulerian chemical-transport model with a spatial resolution of 1 km × 1 km and 30 vertical levels. Meteorological fields were provided by Weather Research and Forecasting Advanced Research (WRF-ARW) version 3.7.1 (Skamarock and Klemp, 2008), using the BEP (Building Effect Parameterization) urban parameterization (de la Paz et al., 2016). Emissions were processed by the Sparse Matrix Operator Kernel Emission (SMOKEV3.6.5) (UNC, 2015) and come from a very detailed urban emission inventory that includes more than 400 traffic-related emission categories (Borge et al., 2018; Pérez et al., 2019) and is consistent with the methodology used for the compilation of Madrid's local official emission inventory. Ambient air pollution levels were simulated using Community Multiscale Air Quality (CMAQ) version 5.0.2 (Byun and Schere, 2006). Further details regarding model set-up can be found in Borge et al. (2018).

We performed two annual runs (1-h temporal resolution) with identical meteorology and configuration except for emission inputs. The baseline air-quality scenario corresponding to 2012 was used to reflect air pollutant levels prior to the implementation of Plan A. The projected, future air-quality scenario was designed to simulate air pollution distribution in 2020 under the assumption of the full implementation of the 30 measures contained in the Plan. As a whole, this stratgy was estimated to reduce NO_X emissions in Madrid by 20% (3011 t yr^{-1}) and $PM_{2.5}$ emissions by 27% (222 t yr^{-1}).

Population and mortality data

The city of Madrid, captial of Spain located in the centre of the Iberian Peninsula, consists of 21 districts with a total population over 3.2 million inhabitants. We used population and daily mortality stratified by age, sex and district according to the official data and projections of the Department for Statistics of Madrid City Council. The number of deaths corresponding to total non-accidental causes (International Classification of Diseases, 10th revision [ICD-10], codes A00-R99), diseases for 2012 were provided by the Madrid Regional Statistical Office under a specific confidentiality protocol, approved by the Carlos III Health Institute Ethics Committee (reference: CEI-PI 21_2018).

Concentration-Response Functions (CRF)

According to the guidelines provided by the Horizon 2020 European project ICARUS, we used the CRFs proposed by two relevant WHO projects; "Health risks of air pollution in Europe-HRAPIE" (WHO, 2013a) and "Review of evidence on health aspects of air pollution-REVIHAAP" (WHO, 2013b) to calculate the number of attributable annual deaths corresponding to all non-accidental causes (ICD-10: A00-R99) among all-ages and the adult population (>30 years old) for each district and for Madrid city overall. This health impact assessment was conducted dependant on health-data availability. The estimations of the impact of long-term exposure and the 95% confidence intervals (CI) associated with each CRF were calculated by means of:

- $PM_{2.5}$ annual mean concentrations for all-cause (natural) mortality in adult populations (age > 30) (Hoek et al., 2013)
- NO_2 annual mean concentrations for all-cause (natural) mortality in adult populations (age > 30) (Atkinson et al., 2018; Hoek et al., 2013)
- O_3 summer months' (April–September) average of daily maximum running 8-h means above a 70 µg m^{-3} concentration for respiratory mortality in adult populations (Jerrett et al., 2009)

Izquierdo et al. (2020) assessed short-term effects as well and concluded that health benefits of Madrid's Plan A were mainly related to reductions of long-term exposure.

RESULTS

According to our simulations, the implementation of Plan A would imply a reduction in the Madrid citywide annual mean $PM_{2.5}$ concentration of 0.6 µg m^{-3} and 4.0 µg m^{-3} for NO_2. In contrast, an increase of 1 µg m^{-3} for O_3 would be expected due to the reduction of NO_X emissions (Saiz-Lopez et al., 2017). The variation of annual mean concentrations (2020-2012) aggregated at district level for the pollutants of interest are shown in Figure 1.

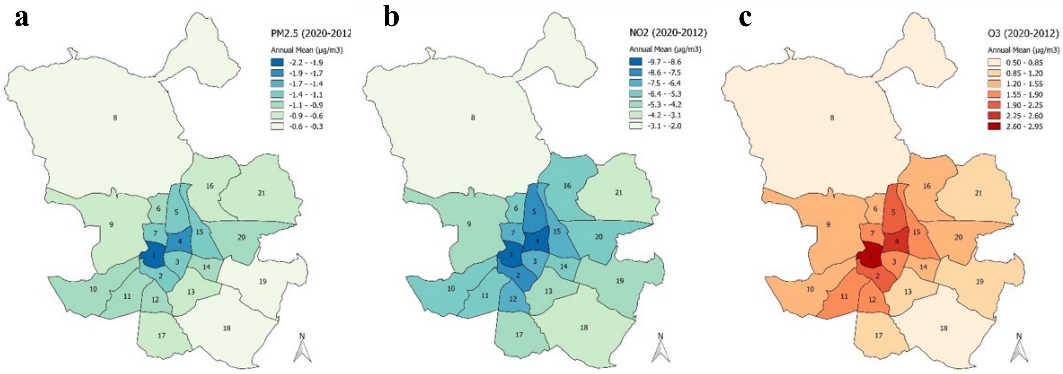

Figure 1. Modelled annual mean concentrations changes (µg m^{-3}) of $PM_{2.5}$ (a), NO_2 (b) and O_3 (c) in the 2012-reference air-quality and 2020-projected air-quality scenarios (negative values imply air quality improvements). Adapted from Izquierdo et al. (2020).

Table 1. Summary of long-term, all-cause mortality (ICD-10: A00-R99) changes caused by Plan A in Madrid city. Negative values mean avoided premature deaths.

Mortality indicator	Pollutant	Reference	Sex	Deaths in absolute numbers (95% confidence interval in brackets)
All-natural causes	$PM_{2.5}$	Hoek et al. (2013)	Total	−88 (−57, −117)
			Men	−41 (−27, −55)
			Women	−47 (−30, −62)
All-natural causes	NO_2	Hoek et al. (2013)	Total	−519 (−295, −750)
			Men	−244 (−139, −353)
			Women	−275 (−156, −397)
Respiratory diseases	O_3	Jerrett et al. (2009)	Total	0 (0, 0)
			Men	0 (0, 0)
			Women	0 (0, 0)

The greatest estimated air quality improvements and therefore, relative health benefits for long-term effects related to decreases in $PM_{2.5}$ and NO_2 levels were in the districts donwton where emissions abatements from road traffic are expected to be more intense due to measures such as the Low Emission Zone ”Madrid Central” (district 1). The HIA results, summarized in Table 1, point out that the annual number of all-cause deaths from long-term exposure (95% CI) that could be postponed in the adult population by the expected air-pollutant concentration reduction was 88 (57–117) for $PM_{2.5}$ and 519 (295–750) for NO_2. While a very slight increase of short-term mortality could be associated to O_3 according to Izquierdo et al. (2020), no long-term effects are expeted regarding this secondary pollutant.

Although the relative risk associated to $PM_{2.5}$ exposure is larger than that of NO_2, 1.062 (1.040–1.083) and 1.055 (1.031–1.080) per 10 µg m^{-3} increment, respectively, health benefits derived from Plan A would be mostly related to the reduction of NO_2 levels since improvements for this pollutant are considerably larger, up to 10 µg m^{-3} for some disctricts. The distribution of deaths avoided attributable to these reductions is shown in Figure 2. However it should be noted that some of the long-term NO_2 effects (up to 33%) might overlap with effects of long-term $PM_{2.5}$ (WHO, 2013a).

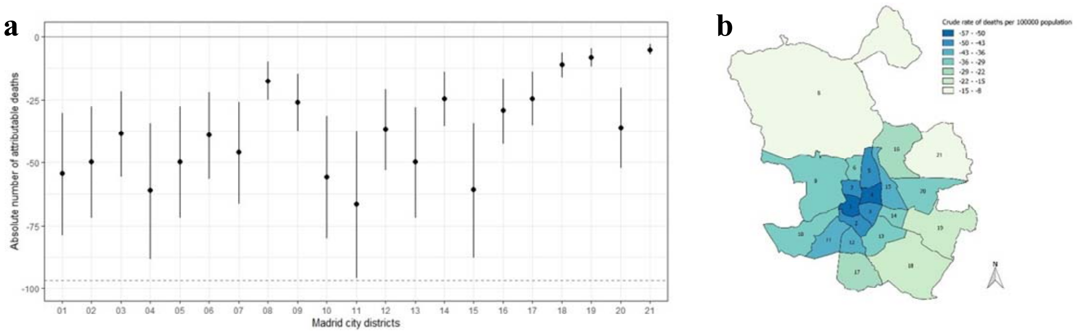

Figure 2. HIA resutls for NO_2 at district level; a) absolute attributable number of deaths and b) crude rate of deaths per 100000 population. Adapted from Izquierdo et al. (2020).

CONCLUSIONS

Within the limitations of this study (furhter details can be found in Izquierdo et al., 2020), we conclude that the effective implementation of Plan A in Madrid city would lead to better air quality and more than 500 all-cause premature deaths could be postponed annually, mainly due to reduced NO_2 ambient concentration levels. Health impact assessments such as this one may enable local governments and other administrations to pay special attention to the groups most affected, thereby preventing inequality in the face of risk and ensuring a just health-benefit distribution. Within-city variations in exposure to air pollution and detected dissimilarities in the potential health benefits achieved across different Madrid districts suggest that furhter strategies should address health inequity by designing measures able to yield larger benefits all over the city. Additional research into O_3 dynamics in Madrid is needed in order to design improved and more comprehensive air-quality control strategies.

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