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HOW DO THE REDUCTION EMISSION MEASURES OF THE SPANISH NATIONAL AIR POLLUTION CONTROL PROGRAMME IMPACT ON STREET-LEVEL AIR QUALITY IN THREE NEIGHBOURHOODS OF MADRID (SPAIN)?

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Abstract: The 1st Spanish National Air Pollution Control Programme (NAPCP) establishes a set of existing and additional measures of emission reductions related to different sectors (electricity generation, road and off-road transport, agriculture, etc.). This study aims to assess the impact of different emission reduction scenarios on air quality at street scale in three highly polluted neighbourhoods in Madrid, Spain. The study scenarios of emission reductions are the projections for 2030 in the 1st Spanish NAPCP with existing and additional measures (WEM2030 and WAM2030, respectively) and a scenario with the emission in 2016. Annual average NO_2 concentrations at high spatial resolution are computed by means of a numerical methodology based on computational fluid dynamics (CFD) simulations driven by mesoscale meteorological and air quality simulations. The results show the importance of considering the spatial variability of NO_2 concentrations within each neighbourhood. Despite the annual mean limit value not being exceeded in any of the study neighbourhoods in terms of the spatially-averaged NO_2 concentrations for the WAM2030 scenario, there are areas with concentrations above this limit within two neighbourhoods.

Key words: *air pollution; Computational Fluid Dynamics (CFD) model; NO_2; national programme; emission control; annual concentrations using CFD*

INTRODUCTION

European countries are committed to reduce annual pollutant emissions to meet the EU limit values regulated under the Air Quality Directive and each country has developed a national programme that includes a set of planned measures. In Spain, the 1st National Air Pollution Control Programme (NAPCP) establishes a set of existing and additional measures of emission reductions related to different sectors (electricity generation, road and off-road transport, agriculture, etc.). NAPCP includes a set of existing measures (WEM2030) and additional measures (WAM2030). More details can be found in Vivanco et al. (2021) and Santiago et al. (2022a).

On the other hand, the interaction between atmosphere and urban surfaces induces complex wind flow and reduced ventilation in the streets. This fact linked with traffic emissions produces high pollutant concentrations with strong gradient in urban environments. Therefore, studies at street scale with high spatial resolution are needed for assessing urban air quality and population exposure (Santiago et al., 2022b).

In this context, the present study is focused on how much different is the model response at different scales to emission reductions at national level. The objective is to investigate the effects of total national emission reductions (projected to 2030) on street-level NO_2 concentrations in three neighborhoods of Madrid (Spain) using mesoscale and computational fluid dynamic (CFD) modelling.

STUDY URBAN AREAS

Three highly polluted neighbourhood of Madrid, Spain are investigated:

- Plaza Elíptica (PE): A heavily trafficked roundabout with a freeway passing under it through a tunnel.
- Escuelas Aguirre (EA): A zone with avenues and streets with intense traffic in the North and a large park in the South.
- Plaza del Carmen (PC): It is characterized by a wide pedestrian zone and an avenue with intense traffic in 2016 (reference year of the study).

METHODOLOGY

Two scenarios of emission reductions are investigated:

- WEM2030 scenario: emissions projected to 2030 assuming existing measures in the current legislation. The total NOx reduction is 7 % and the NOx reduction for road transport is also 7 %.
- WAM2030 scenario: emissions projected to 2030 assuming additional measures of NAPCP. The total NOx reduction is 33 % and the NOx reduction for road transport is also 48 %.

In addition, a Base scenario with the emissions of 2016 is simulated. The effects of the measures on air quality are computed as the differences in pollutant concentrations between emission reduction scenarios and the base case (2016 emissions) under the same meteorological conditions. However, it is not an assessment of the NAPCP.

Annual mean NO_2 concentrations at high spatial resolution are computed using a numerical methodology (WA CFD-RANS) based on computational fluid dynamic (CFD) modelling. NOx dispersion is simulated for 16 wind directions and different emissions. At each hour, wind direction and the value of reference velocity provided by mesoscale meteorological simulations are used for selecting the most appropiate CFD simulation from the set of simulations and for modifying the simulated concentrations (concentrations are inversely proportional to wind speed). NO_2 concentrations are estimated using the ratio NO_2/NOx computed by air quality mesoscale simulations of CHIMERE at surface level. In addition, background concentration is added to NO_2 modelled using concentrations of CHIMERE at the mixing height. Although, if the mixing height if higher than 1.5 times the height of tallest building (1.5 H_{max}), the concentration at 1.5 H_{max} is used. In this point, there is a difference with Santiago et al. (2022a). Another difference is the spatial resolution of CHIMERE that, in this case, is 1 km x 1 km approximately. More details about the methodology can be found in Sanchez et al. (2017), Rivas et al. (2019) and Santiago et al. (2022a). CFD simulations are based on Reynolds-averaged Navier-Stokes equations with realizable k-ε turbulence model. Aerodynamic effects of vegetation are also modelled. A transport equation is used to simulate the NOx dispersion and only traffic emissions are taken into account in CFD simulations. Traffic emissions are located in roads using mean daily traffic of each street. For all scenarios, only reductions of traffic emissions are considered in CFD simulations (7 % for WEM2030 scenario and 33% for WAM2030 scenario). Background concentrations take into account other pollutant sources. Spatial resolution is around 1 m close to the building. The total number of cells ranges from 3 to 9 millions of cells depending on the neighbourhood. More details about numerical domains and meshes can be found at Sanchez et al. (2017) and Santiago et al. (2020) for PE, Santiago et al. (2017) for EA and Borge et al. (2018) for PC.

RESULTS

Annual mean NO_2 concentrations at high spatial resolution are computed for the three neighbourhoods. Firstly, time series of modelled NO_2 for 2016 emissions are succesfully evaluted using concentrations recorded at air quality monitoring stations (AQMS) inside each neighbourhood (Figure 1). Note that a similar methodology applied to these areas was succesfully evaluated in previous studies using extenisve passive samplers campaigns (Santiago et al., 2017 and Sanchez et al., 2017).

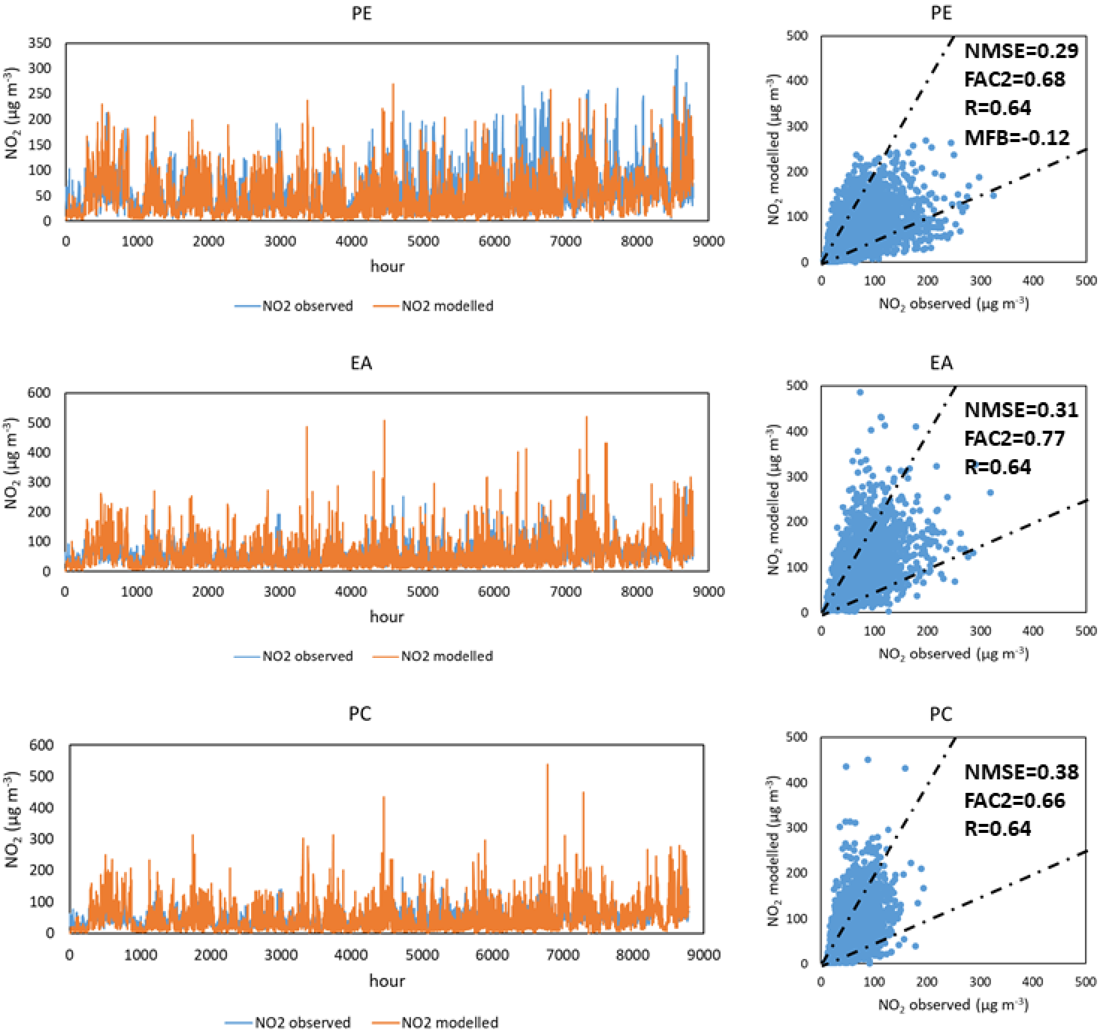

Figure 1. Time series and scatter plots of observed and modelled NO_2 concentrations at PE AQMS (top), EA AQMS (middle) and PC AQMS (bottom).

Figures 2, 3 and 4 shows the annual mean NO_2 concentrations at high spatial resolution in PE, EA and PC neighbourhood respectively.

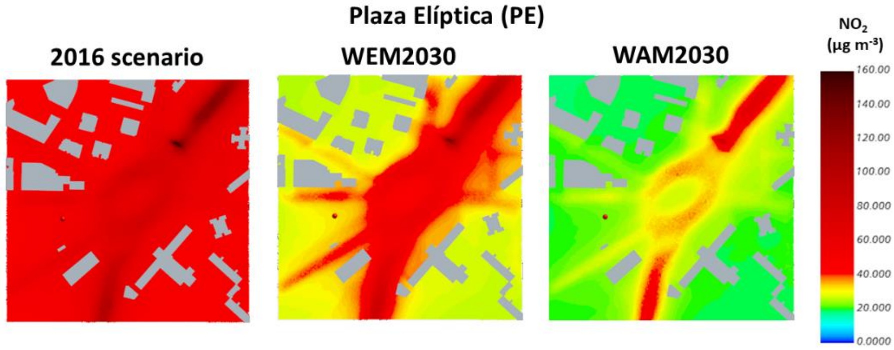

Figure 2. Annual mean NO_2 concentrations at high spatial resolution for 2016, WEM2030 and WAM2030 emission scenarios in Plaza Elíptica.

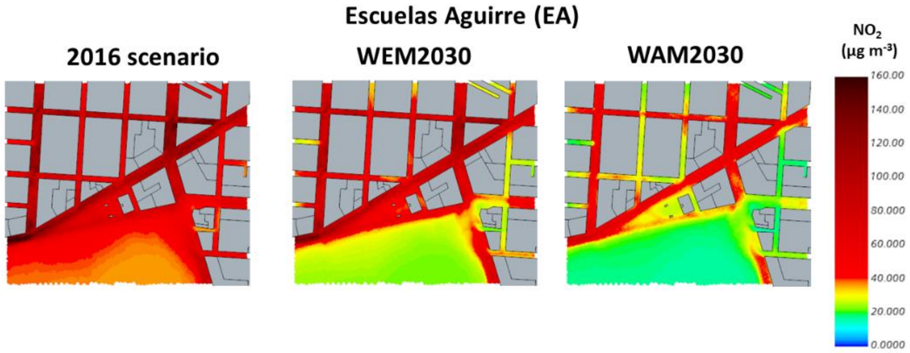

Figure 3. Annual mean NO_2 concentrations at high spatial resolution for 2016, WEM2030 and WAM2030 emission scenarios in Escuelas Aguirre.

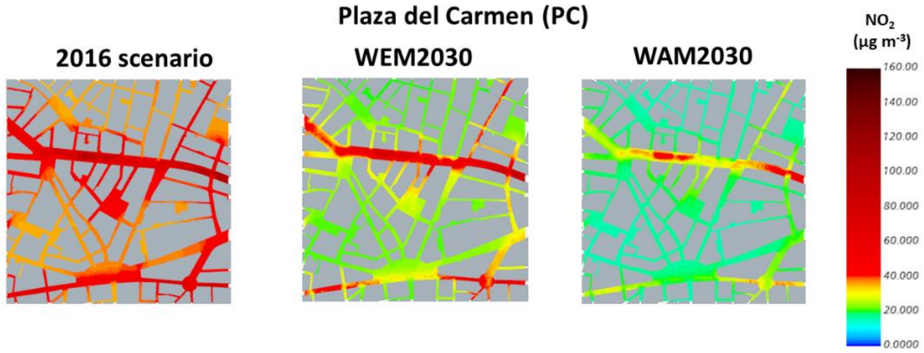

Figure 4. Annual mean NO_2 concentrations at high spatial resolution for 2016, WEM2030 and WAM2030 emission scenarios in Plaza del Carmen.

It is observed that WAM2030 scenario is much more effective than WEM2030. However, for WAM2030 there are zones with concentrations above the limit value. Spatially-averaged annual NO_2 concentrations are computed for each neighbourhood and for the three emission scenarios (Figure 5). For WEM2030 scenario, the limit value is only exceeded in EA neighbourhood and for WAM2030 the limit value is not exceed in any case.

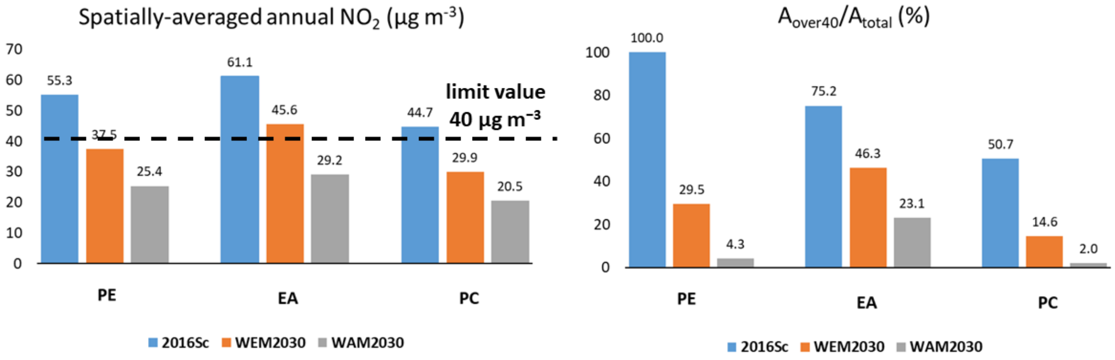

Figure 5. Spatially-averaged annual NO_2 concentrations for each neighbourhood for the three emission scenarios (left) and ratio (in %) between the area above the annual average limit value for NO_2 (40 µg m^{-3}) (A_{over40}) and the total study area (A_{total}) for each neighbourhood and for the three scenarios (right).

Areas with concentrations above the annual limit values within each neighbourhood are found for the three neighbourhoods, even for WAM2030 scenario (Figure 5).

CONCLUSIONS

WAM2030 scenario is much more effective than WEM2030. Despite the annual mean limit value not being exceeded in any of the study neighbourhoods in terms of spatially-averaged NO2 concentrations for the WAM2030 scenario, there are areas with concentrations above 40 µg m^{-3} within each neighbourhood. Therefore, annual mean limit could be exceeded in some areas within the mesoscale cells in urban areas in spite of the spatially-averaged annual mean NO_2 concentration being below the limit value. In conclusion, to estimate population exposure and air quality assessment in urban environments, it is important to take into account the spatial variability of NO_2 concentrations within each neighbourhood.

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