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Evaluating strategies to reduce urban air pollution

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HIGHLIGHTS

- We investigate measures to reduce PM and NO_2 ambient levels over Porto urban area.
- We use the TAPM numerical modelling tool.
- Measures for traffic sector, industry and residential combustion have been selected.
- To reduce PM10 measures should be focused on residential combustion and industry.
- For NO2 the strategy should be based on the traffic sector.
- Implementation of all scenarios allows a maximum reduction of 4.5% for both pollutants.

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ABSTRACT

During the last years, specific air quality problems have been detected in the urban area of Porto (Portugal). Both PM10 and NO_2 limit values have been surpassed in several air quality monitoring stations and, following the European legislation requirements, Air Quality Plans were designed and implemented to reduce those levels. In this sense, measures to decrease PM10 and NO_2 emissions have been selected, these mainly related to the traffic sector, but also regarding the industrial and residential combustion sectors. The main objective of this study is to investigate the efficiency of these reduction measures with regard to the improvement of PM10 and NO_2 concentration levels over the Porto urban region using a numerical modelling tool – The Air Pollution Model (TAPM). TAPM was applied over the study region, for a simulation domain of 80×80 km^2 with a spatial resolution of 1×1 km^2. The entire year of 2012 was simulated and set as the base year for the analysis of the impacts of the selected measures. Taking into account the main activity sectors, four main scenarios have been defined and simulated, with focus on: (1) hybrid cars; (2) a Low Emission Zone (LEZ); (3) fireplaces and (4) industry. The modelling results indicate that measures to reduce PM10 should be focused on residential combustion (fireplaces) and industrial activity and for NO_2 the strategy should be based on the traffic sector. The implementation of all the defined scenarios will allow a total maximum reduction of 4.5% on the levels of both pollutants.

1. Introduction

Air quality is one of the environmental areas in which the European Union (EU) has been most active, in particular designing and implementing legislation on air quality and on the restriction of pollutant emissions to the atmosphere. The Directive on Ambient Air Quality and Cleaner Air for Europe (Directive 2008/50/EC), published in May 2008, highlights modelling as a fundamental tool to improve air quality assessments and management. The Directive also reinforces the obligation of EU member states to elaborate and implement Air Quality Plans (AQP) to improve air quality when standards are not fulfilled. The implementation of AQP, when pollutant concentrations exceed the air quality standards in zones or agglomerations, should be based on the development of measures that reduce the pollutant atmospheric concentrations and meet the legal requirements (Miranda et al., 2014, 2015).

Exceedances of the thresholds of particulate matter (PM10) and nitrogen dioxide (NO_2) have been reported in the urban agglomeration of Porto Litoral, where human exposure is also high

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(Borrego et al., 2009; Miranda et al., 2014). Air Quality Plans were developed for both pollutants: during the period 2005–2008 for PM10 (Borrego et al., 2010) and in 2010 for NO_2 (Borrego et al., 2012a). Despite improvements in air quality, verified after the 2008–2010 period, there is still a requirement for the reduction of the concentrations of these pollutants, because some of the legislated limits continue to be exceeded every year in particular monitoring sites.

Due to their ability in assessing the efficiency of different emission reduction measures, air quality numerical models are useful tools for air quality management. They estimate pollutant concentrations in areas that are not covered by air quality monitoring stations and quantify the impact of projected emission scenarios on air quality. Air quality models have been used by several Member States in the scope of designing AQP for European zones/agglomerations (Nagl et al., 2007). Eulerian Chemical Transport Models (CTM) are the most frequently used (APPRAISAL, 2013), requiring the emissions estimated for several activity sectors, meteorological variables and initial and boundary conditions as input data. The Air Pollution Model (TAPM) (Hurley et al., 2005) is particularly suited to evaluate the impact of emission reduction strategies due to its flexibility, user friendly environment and short time demands in terms of computational efforts for long term simulations (1 year) compared to other CTM models. TAPM has been previously applied and validated over several Portuguese areas (Borrego et al., 2012b).

The main objective of this study is to investigate the most efficient measures to reduce PM10 and NO_2 concentration levels, quantifying this reduction and supporting future additional AQP and policy makers for the air quality management over urban areas, such as the Porto Litoral agglomeration. The present work is organized as follows: Section 2 presents the PM10 and NO_2 concentrations registered over the last decade, followed by description of the air quality modelling system and its setup/application over the Porto urban region in Section 3. The measures (emission reduction scenarios) to reduce PM10 and NO_2 concentrations are proposed in Section 4, their efficiency/impact analysed and discussed in Section 5. Finally, the summary and conclusions are drawn in Section 6.

2. PM10 and NO_2 measured in the porto urban region

Fig. 1 presents the evolution of the annual mean concentrations of PM10 and NO_2, together with the number of days in exceedance regarding the daily legal limits, registered between 2004 and 2013 in the monitoring sites located in the Porto metropolitan area.

Regarding PM10, the exceedances to the annual and daily limit values (Fig. 1a,b) decreased significantly after the implementation of the 2008 AQP for PM10. For NO_2, the air quality improvement after this AQP is less notorious (Fig. 1c, d). Besides the AQP strategy, the financial crisis also contributed to the reduction of pollutant emissions and consequently to the air quality improvement (Ribeiro et al., 2014).

The average daily profiles of PM10 and NO_2, displayed in Fig. 2, enable the understanding and characterization of the major causes of measured levels at the different monitoring sites.

The PM10 daily profiles, grouped by season, show that the highest concentrations are observed at night, reaching maximum values during the winter period which can be related to residential combustion activities. Regarding NO_2, the daily profiles (similar behaviour between the seasons) follow the traffic diurnal cycle, with peaks in the morning and late afternoon. This characterization supported the establishment of more appropriate emission reduction scenarios to mitigate concentrations of these pollutants.

In order to evaluate the impact of the proposed measures on the improvement of atmospheric PM10 and NO_2 levels, the air quality modelling system TAPM (Section 3) was applied to the current situation (base scenario) and to several emission reduction scenarios (Section 4).

3. Air quality modelling system

The model selected to perform the air quality simulation over the study region was “The Air Pollution Model” (TAPM) (Hurley et al., 2005), developed by Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO). This model is a 3-D Eulerian model, made of two modules which calculate meteorological conditions and air pollution concentrations based on fundamental fluid dynamics and scalar transport equations. Technical details of the model equations, physical and chemical parameterisations, as well as its numerical methods, are described by Hurley et al. (2005).

In the TAPM meteorological module, global databases of terrain and land use from the Earth Resources Observation Systems (EROS), surface temperature from the US National Centre for Atmospheric Research (NCAR), and synoptic conditions from the Limited Area Prediction System (LAPS) and Global Analysis and Prediction (GASP) models from the Bureau of Meteorology (BOM) were used. This module solves the momentum equations for horizontal wind components, the incompressible continuity equation for the vertical velocity in a terrain-following coordinate system, and scalar equations for potential virtual temperature, specific humidity of water vapour, cloud water and rain water. This first module provides the meteorological forcing necessary for the air quality simulation.

The air pollution module of TAPM consists of an Eulerian grid-based set of prognostic equations for pollutant concentration, with optional pollutant cross-correlation equations to represent counter-gradient fluxes, and an optional Lagrangian particle mode for near-source concentrations. The Eulerian grid module was applied and consists of nested grid-based solutions of the Eulerian mean concentration and optional variance equations representing advection, diffusion, chemical reactions and emissions. Dry and wet deposition processes are also included. Besides the meteorological outputs, the air pollution module considers the air pollutant emissions from several sources, such as: point sources, line sources, gridded surface emissions, biogenic surface emissions, among others. Regarding the simulation of the point sources, plume buoyancy, momentum and building wake effects are considered. The model was run in chemistry mode, with gas-phase based on a semi-empirical mechanism entitled the Generic Reaction Set (GRS), including 10 reactions for 13 species (Hurley et al., 2005).

TAPM was applied over the study region using synoptic data provided by CSIRO. The application considered three domains using a nesting approach: the outer domain includes part of the Iberian Peninsula (D1), D2 covers Northern and Central Regions of Portugal, and the inner domain contains the Porto urban area (D3), with a resolution of 10, 3 and 1 km^2, respectively. The air pollution module, using chemistry mode, was applied for the inner domain (D3) with an area of 80 $\times$ 80 km^2 (see Fig. S1-Supplementary material).

TAPM was applied for the year 2012, corresponding to the most updated national emission inventory report (APA, 2014). The annual emissions information is disaggregated by municipality and divided by SNAP categories: commercial and residential combustion (SNAP2); industrial combustion (SNAP3); production processes (SNAP4); extraction and distribution of fossil fuels and geothermal energy (SNAP5); solvent and other product use (SNAP6); road transport (SNAP7); other mobile sources and machinery (SNAP8); waste treatment and disposal (SNAP9). The