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PLANS AND PROGRAMMES TO IMPROVE AIR QUALITY OVER PORTUGAL: A NUMERICAL MODELLING APPROACH

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Abstract: Over the last decade, air pollution has become a major problem in Portugal mainly due to the high concentration of particulate matter (PM10) in the atmosphere. The PM10 annual and daily limit values have been surpassed in several Portuguese agglomerations and, according to the European legislation, plans and programmes must be designed and implemented to reduce those PM10 levels.
The Northern region of Portugal includes some agglomerations that have to design plans and programmes for the improvement of the air quality, in particular concerning PM10. Seventeen measures have been defined for six main sectors, namely traffic, industry, residential combustion, constructions, agriculture and forests. Additional measures will also be applied at national level (e.g., certified residential combustion devices and the inclusion of particulate matter filters in heavy vehicles). The implementation of these measures must be accomplished by the end of 2011 and will lead to nearly 50% reduction on PM10 emissions in the Northern region of Portugal. The main objective of this study is to investigate the impact of all designed measures on the air quality of Northern Portugal. The Air Pollution Model (TAPM) was applied over the study region, for a 120×120 km^2 simulation domain with 4.8 km spatial resolution. The TAPM model was applied to the year 2004, which is the base year for the analysis of the selected measures. Two scenarios have been defined and simulated: the reference situation which considers the current PM10 emissions; and, the reduction scenario where the PM10 emissions were re-estimated taking into account the implementation of all measures.
The modelling results point to PM10 daily averaged concentration decreases 4.6 $\mu g.m^{-3}$ over the Porto urban area, which corresponds to a 19% reduction in the PM10 levels. Moreover, results indicate that the implementation of the selected measures will allow the accomplishment of the PM10 legislation in some air quality stations on the Northern Region of Portugal.

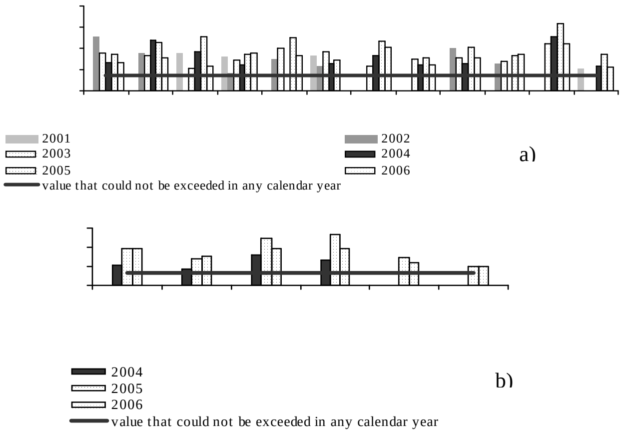
Key words: *PM10 emissions, PM10 levels, plans and programmes, air quality modelling*

INTRODUCTION

Air quality is one of the environmental areas in which the European Union (EU) has been most active, namely in the design and implementation of legislation on air quality and pollutant emissions to the atmosphere. In order to reduce and control the effects of air pollution on human health and in the environment, the air quality directives require the EU member states to assess air quality through their territory. At the European level the air quality Framework Directive (FD) (Directive 96/62/CE of September 27), established the obligations of the member states and redefined the guidelines for the assessment and management of air quality. In May 2008, a new Directive on Ambient Air Quality and Cleaner Air for Europe (Directive 2008/50/EC) was published, merging four directives and one Council decision into a single document. This new directive introduces new objectives for fine particles, but does not change existing air quality standards. Additionally, the application of numerical models is highlighted in this new Directive as a fundamental tool to better assess and manage air quality. One of the main aims is the implementation of air quality plans and programmes (PP) when the air pollutant concentrations exceed the target or limit values (LV) in zones or agglomerations. The implementation of PP is based on the design of measures in order to reduce the air pollutants atmospheric concentrations and meet the legal requirements.
Particulate matter with a 50 % efficiency cut-off at 10 μm aerodynamic diameter (PM10) thresholds exceedances have been reported by the majority of the EU member states, mainly in urban agglomerations, where human exposure is also higher (EEA, 2005). For PM10 the daily limit value is of 50 $\mu g.m^{-3}$ plus the margin of tolerance (LV+MT) and cannot be exceeded more than 35 times in a calendar year. Portugal, over the last years, has been surpassing the legislated limit values for PM10 concentrations in ambient air at several air quality monitoring stations (Monteiro *et al.*, 2007) over two main regions: Lisboa and Vale do Tejo region and the Northern region. These regions are by law obliged to design and implement PP to reduce the PM10 concentrations The main sources of PM10 emissions are anthropogenic and natural, in particular the Saharan dust, forest fires and sea spray (Borrego *et al*., 2008a). The anthropogenic sources of PM10 are usually located in the urban and industrial areas. Over the urban areas, the emission of PM10 is related to residential combustion, civil constructions and road traffic. This study will focus on the Northern part of Portugal which has two zones and four agglomerations namely, Porto Litoral, Braga, Vale do Sousa and Vale do Ave. A total of 23 air quality monitoring stations are located over the study region, where more than half are in Porto Litoral agglomeration (Borrego *et al.*, 2008b).
A detailed analysis of the main anthropogenic sources of PM10 emissions has been accomplished and seventeen reduction measures have been designed for the Northern region for six main sectors: traffic, industry, residential combustion, constructions, agriculture and forests. At national level additional measures had been considered. The main objective of this study is to evaluate the impacts of the reduction measures on the PM10 levels in the atmosphere of Northern Portugal.

2 - PM10 CHARACTERIZATION OVER THE STUDY REGION

The PM information described on the national emissions inventory performed under the Convention on Long-range Transboundary Air Pollution for the period 1990-2006 allows the analysis of the PM emissions in Portugal. They increased almost 44% along the 1990 - 2006's period (Borrego *et al.*, 2009). Based on a regional emission inventory for the Northern Portugal region (Borrego *et al.*, 2008a and 2010) it was possible to list the main PM10 emitting activity sectors: industrial, residential and commercial and traffic (road, sea, air and rail). An analysis of data from all the air quality monitoring stations, for the period 2001 – 2006, of the Northern Portugal region was performed to identify the stations and the agglomerations that were not accomplishing the legislated values. The agglomerations Porto Litoral, Vale do Ave and Vale do Sousa, accordingly to the Directive, were facing air quality problems regarding the PM10 concentration levels. Figure shows the total number of exceedances to the daily limit value plus the margin of tolerance, if applicable, for the considered years.



ANT-Antas;
BOA-Boavista;
MAT-Matosinhos;
SHOR – Senhora da Hora;
ESP-Espinho;
VER-Vermoim;
PAR-Paredes;
GUI-Guimarães;
CIR-Circular Sul;
ERM-Ermesinde;
LAT-Centro Lacticínios;
STIR-Santo Tirso;
PER-Perafita;
CUS-Custóias;
VCON-Vila do Conde;
LBal-Leça do Balio;
VNT-Vila Nova da Telha;
CAL-Calendário

Figure 1 – Nr. of exceedances in a) Porto Litoral and b) Vale do Ave, Vale do Sousa and Braga agglomerations to 2001-2006.

A study was performed to investigate the causes of the high values of PM for the period 2001-2006 (Borrego *et al.*, 2008b) showing an increase of the anthropogenic contribution on the exceedances through the years. According to the legislation the daily limit value for PM10 levels should not be exceed more than 35 days in a calendar year. For the period between 2001 and 2006, this limit has been exceeded in all stations (Figure 1). Thus, the development of plans and programmes for the reduction of PM10 emissions is mandatory for the improvement of air quality.

3 – PM10 REDUCTION MEASURES

An analysis of the strategies already legislated and applied should precede the definition of the measures to improve air quality and therefore delineate the base scenario. If the outcomes of these already established measures are not enough to accomplish the air quality limit values within the agglomerations, additional measures have to be defined (reduction scenario). The additional measures were mainly oriented towards three key sectors of the PM10 emissions in Portugal: traffic, industry, and residential and commercial combustion (Borrego *et al.*, 2008b). Some examples of the measures are described in Table .

Table 1 – Examples of the PM10 reduction measures selected for the Northern Region (Borrego et al., 2008b).

Sector	Measure
Traffic	Introduction of public transportation with lower emission and improvement of public transport network
	Renewal of taxis and solid waste collection vehicles
	Decrease of heavy vehicles circulation in the urban areas
	Areas with reduced emissions in urban areas
	Cut of traffic roads
Industry	Improvement of industrial PM retention systems
	Reinforcement of the inspection of industry sources
	Establishment of emissions standards for industrial clusters and business activities in urban areas
Residential combustion	Use of certified combustion appliances with PM emissions reduction

In the traffic sector the emissions reduction was calculated using national emissions factors for different age and circulation speed of each vehicle. If better PM retention systems will be used at the industrial sector a 50% reduction of PM10 is expected for the wood and cork industries and 17% reduction for the entire Northern Region. At the end, the foreseen emissions reduction values are: for the residential and commercial combustion sector 92% for all the Northern Region; for the industry sector 50% for all the Northern Region, excluding Vila Nova de Famalicão (45%) and Matosinhos (18%); for traffic sector, since it is different for each local, the mean value is 14%, with the maximum reduction of 28% and the lowest reduction of 1%.

4 – AIR QUALITY MODELLING

To study the effects of the selected PM10 reduction measures, the air quality modelling system TAPM (Hurley *et al.*, 2005) was applied over Northern region for one year (2004).

4.1 – Air quality modelling system

The Air Pollution Model (TAPM) is a 3-D Eulerian model, with nesting capabilities, which predicts meteorology and air pollution concentrations in a Graphical User Interface. The model has two components: the meteorological prognostic, and the air pollution concentrations component. The meteorological module of TAPM is an incompressible, optionally non-hydrostatic, primitive equation model with terrain-following coordinates for 3D simulations. The results from the meteorological module are one of the inputs to the air pollution component of TAPM. The air pollution component includes various sub-modules: Eulerian Grid Module (EGM), Lagrangian Particle Module (LPM), Plume Rise Module (PRM) and Building Wake Module (BWM). In this study the EGM sub-module was applied and consists of nested grid-based solutions of the Eulerian concentration mean and optionally variance equations representing advection, diffusion, chemical reactions and emissions, the dry and wet deposition processes are also included.

4.2 – Air quality modelling application

In order to investigate the impact of the designed PM10 reduction measures on the air quality of the Northern Portugal, TAPM was applied over the study region, which includes the agglomerations of Porto Litoral, Vale do Ave and Vale do Sousa, where the PM10 concentrations exceeded the legislated limit values. The application considered three domains through the nesting approach: the outer domain covers an area of 1080×1080 km^2 with a spatial resolution of 43.2×43.2 km^2 and the inner domain with an area of 120×120 km^2 with a resolution of 4.8×4.8 km^2. TAPM was applied along the year 2004, which is the base year for the analysis of the selected measures, for two different emissions scenarios: base scenario and reduction scenario. For the base scenario, annual emissions data were obtained from the Portuguese national inventory, spatially downscaled to the sub-municipality level for each pollutant and each activity sector. The national emissions inventory takes into account annual emissions from line sources (streets and highways), area sources (industrial and residential combustion, solvents and others) and large point sources. These annual emission data for each pollutant and activity sector were spatially and temporally disaggregated in order to obtain the resolution required for the study domain simulation. For the reduction scenario the emissions values of PM10 were estimated based on the implementation of the selected reduction measures. The background concentrations required by the model were obtained estimating the mean of the values of the background air quality stations of the study area for 2004.

The meteorological and air quality simulations were performed for the defined domains over the study region. A validation for the base scenario was performed for the inner domain, which includes all the air quality stations. Three quality indicators have been estimated to evaluate the TAPM performance over the study region, namely: Index of Agreement (IOA), Measures of Skill (SKILLr) and Bias (BIAS) (Hurley *et al.*, 2005).

4.3 – Air quality modelling results

A statistical analysis of the modeling system skills was made. The meteorological module performance was evaluated against the observed values of temperature and the horizontal wind components (U and V) at two different meteorological stations of the Northern region (Pedras Rubras Porto and Viana do Castelo) Table summarizes the model performance for temperature and wind at the two weather stations located in the Northern region. .

Table 2 – TAPM performance statistics for temperature (ºC) and the horizontal wind components (m.s-1).

	Pedras Rubras			Viana do Castelo		
	TEMP	U	V	TEMP	U	V
IOA	0.94	0.79	0.86	0.91	0.66	0.74
SKILLr	0.46	1.03	0.83	0.63	1.39	1.00
BIAS	0.46	-0.83	-0.21	-0.94	-0.76	-0.48

The TAPM shows a good performance simulating both temperature and wind components, with no significant biases, low SKILLr and high IOA for both meteorological stations. Pedras Rubras presents a slightly better performance than Viana do Castelo station.

The same statistical indicators have been applied for the PM10 simulated values at the air quality stations that presented exceedances to the limit values. Only the air quality stations with acquisition efficiency above 75% were used. Figure 2 presents the IOA for each air quality station, for the base scenario simulation.

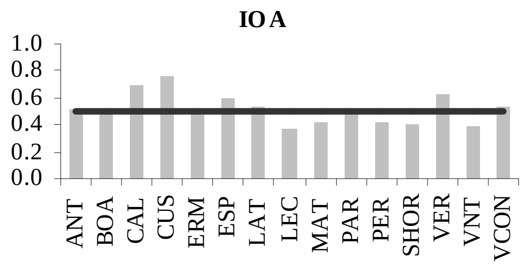


Figure 2 – IOA statistical indicator for each air quality station for the TAPM base scenario simulation for the year 2004.

According to Figure 2, only some air quality stations have an IOA higher than 0.5 highlighting the model difficulties to simulate the PM10 values in the study region. The negative BIAS (not shown) over all the air quality stations reveals a clear underestimation of the measured PM10 concentrations. The SKILLr also presents a very poor score. These poor skills could be explained by the complexity of the terrain of the study area, which is not correctly simulated with a 4.8 km x 4.8 km spatial resolution, and by the uncertainty of the used emissions. Notwithstanding this evaluation, TAPM could be an important tool for the decision makers to assess the efficiency of the measures selected in PP. It can simulate rapidly different emission scenarios allowing their comparison and facilitating the decision making.

In order to study the effects of the application of all the selected measures on the air quality, the reduction scenario was also simulated with TAPM. Figure shows the spatial differences between the reduction and the base scenarios results in terms of the annual mean PM10 concentrations absolute values (a) and percentages (b).

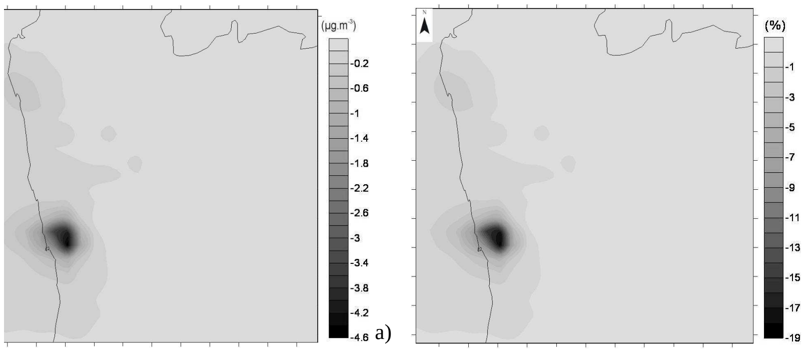


Figure 3 – PM10 annual mean concentration differences between the reduction scenario and the base scenario concerning absolute values (a) and percentages (b).

According to Figure 3 the maximum absolute reduction is achieved over the Porto region and reaches 4.6 μg.m^{-3} that corresponds to a 19% reduction of the PM10 average levels in the atmosphere.
Another way to study the effects of the reduction measures consists in estimating the reduction obtained by the comparison of the results from each scenario simulation (base and reduction) for each day and then applying this reduction profile to the daily observed values. This approach has only been applied to the air quality stations with IOA higher than 0.5. Figure illustrates the annual mean, the number of exceedances based on the observed values and based on the observed values after the application of the reduction profile.

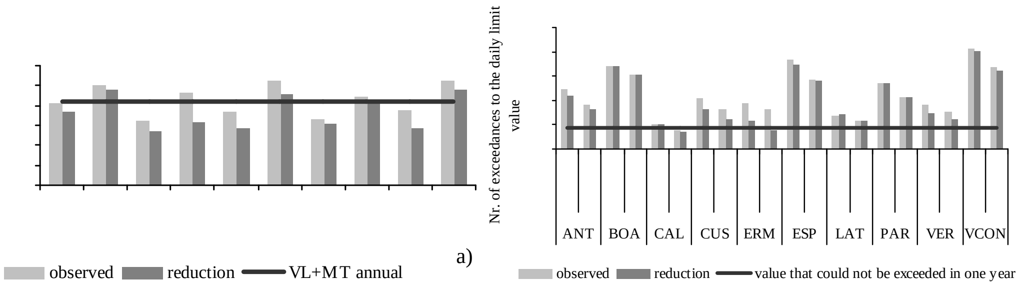


Figure 4 – PM10 annual mean (a) and number of exceedances (b) for the observed values and for the observed values after the application of the reduction profile.

According to Figure 4, although the PM10 annual mean and the number of exceedances decrease in the selected air quality stations the legislated limit values continue to be surpassed.

5 – SUMMARY AND CONCLUSIONS

In Northern region of Portugal high PM10 concentrations were measured, namely at several agglomerations. According to the European and national legislation, the limit values have been surpassed in this region and consequently plans and programmes must be designed and implemented to reduce these PM10 levels. For this purpose seventeen reduction measures have been designed at the local level. These measures comprise six main sectors, namely traffic, industry, residential combustion, construction, agriculture and forests, and environmental education, at local level. The impact of all designed measures on the air quality of the Northern Portugal is the main objective of this study. A detailed analysis of the defined measures and of their potential application was carried out with the support of the involved stakeholders in order to better evaluate the resulting emission reduction.
From this study it is possible to conclude that the application of the selected reduction measures is important to reduce the PM10 concentrations observed in the Northern region. A decrease of the annual mean and the number of exceedances was verified in the air quality stations. However, even after the application of the reduction measures, most of the air quality stations continue to surpass the legislated limit values. The modelling results for the reduction scenario show a PM10 daily

averaged concentration decrease of almost 5 $\mu g.m^{-3}$ over the Porto urban area, which corresponds to a 19% maximum reduction. Only with the joint application of all the measures it will be possible to achieve this reduction level. Moreover, this study highlights that additional measures must be applied in order to fulfil the air quality requirements. The involvement of local authorities and stakeholders is very important, but some potential reduction measures, probably the most air quality efficient, should be taken at national level.

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