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# IMPROVING URBAN AIR QUALITY USING A COST-EFFICIENCY AND HEALTH BENEFIT APPROACH

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**Abstract**: Notwithstanding the achievements in emission reductions and air quality improvement in some European urban agglomerations like Grande Porto (Portugal), additional efforts have to be undertaken to improve air quality in a cost-efficient way.. This work focuses on the definition and assessment of emission abatement measures and their associated costs, air quality and health impacts and benefits by means of air quality modelling and cost-benefit analysis tools. The MAPLIA modelling system was applied to the Grande Porto urban area, addressing (particulate matter) PM10 and (nitrogen oxides) NOx, which are the most pertinent pollutants in the region. Four different measures to reduce PM10 and NOx emissions were defined and characterized in terms of emissions and implementation costs, and combined into 15 emission scenarios simulated by an air quality model (TAPM). Air quality concentration fields were then used to estimate health benefits in terms of avoided costs (external costs), using dose-response health impact functions per pollutant for different health indicators (morbidity and mortality). Results revealed that the resulting scenario including all 4 measures lead to a total benefit of 0.3 M€/yr. Among the 15 scenarios analysed, the largest benefit is obtained for the scenario considering the conversion of 50% of open wood stoves into heat recovery wood stoves. Although the implementation costs of this measure are high, the benefits outweigh the costs. The most cost-efficient scenario is the one that combines the heat recovery wood stove measure and the replacement of 10% of passenger cars below EURO3 by hybrid vehicles.

***Key words:*** *Emission abatement measures, air quality modelling, health impact functions, cost-benefit.*

## INTRODUCTION

Urban areas are still facing air pollution problems. The European Commission air quality standards (EU Directive 2008/50/EC) have been exceeded and Members States are obliged to develop and implement Air Quality Plans (AQP) to improve air quality and health (EEA, 2015).

Together with air quality assessment, quantifying the impact of air pollution on the public's health is an important component for the design and evaluation of effective local and regional AQP. The health impact assessment provides an objective estimate of the influence of the mitigation measures in air quality on a given population's health. It uses available epidemiological studies together with routine environmental and health data to evaluate the potential effects of a policy, programme or project on the health of a population, including how those effects are distributed across the population, thus helping decision makers to plan and implement measures to protect public health more effectively. Exposure-response function (ERF) can be used to estimate the risk of developing a disease due to exposure to agents with different levels of intensity and duration (Smith et al., 1999). Hence, an ERF links the concentration of pollutants to which a population is exposed with the number of health events occurring in that population. The appropriate selection of adverse health outcomes and ERF is a critical step. The impact is determined by the relation of two variables: exposure and effect. One or more indicators are used to express the change in population health status due to exposure to an air pollutant. Most health-based indicators are, or derive from, mortality and morbidity endpoints. Thus, to evaluate the health impacts arising from air pollution, the following aspects can be considered: (i) involved pollutants and their air concentration levels; (ii) health indicators analysed in terms of morbidity and mortality; (iii) affected age groups; and (iv) exposure time. These data are used to quantify the extent of these impacts, evaluated through ERFs and health outcome frequencies, which combined with the population exposure to air pollution provides the number of attributable cases/days (Equation 1) (EC, 2005).

$$\Delta R_i = I_{ref} \times CRF_{i,p} \times \Delta C_p \times pop \qquad (1)$$

where:
ΔRi – Response as a function of nr of unfavourable implications (cases, days or episodes) over all health indicators (i = 1,..., n) avoided or not;
Iref – Baseline morbidity/mortality annual rate; pop – Population units exposed to pollutant p;
CRFi,p – Correlation coefficient between pollutant p´s concentration variation and probability of experiencing or avoiding a specific health indicator i (i.e. Relative Risk - RR);
ΔCp – Change in pollutant p´s concentration after adoption of abatement measures (emission scenarios).

When economic values are applied to health endpoints, the monetary costs and benefits of different options can be directly compared (O'Connell and Hurley, 2009). The World Health Organization (WHO) has recently published a set of recommendations for ERF and cost-benefit analysis of key pollutants in support of the European Union's air quality policy revision (WHO, 2013). This report recommends ERF and associated background information for several mortality and morbidity effects associated with short and long-term exposure to particular air pollutants such as PM, ozone ($O_3$) and nitrogen dioxide ($NO_2$). The resulting health impacts are translated into monetary values (i.e. external costs), in order to be properly considered as economic costs. In the recent years, Integrated Assessment Models (IAM) for air quality planning (encompassing health impact assessment) have already been formulated and implemented at the continental and country scales (e.g. Carnevale et al., 2012; Amann et al., 2011). However, they are not specifically addressing the sub-national scale, particularly urban areas where a major share of the European population lives and where health impacts are more pertinent.

This work is focused on the definition and assessment of emission abatement measures and their associated costs, air quality and health impacts and benefits by means of air quality modelling tools and cost-benefit analysis, specifically developed for urban areas in the scope of the recently concluded MAPLIA project "Moving from Air Pollution to Local Integrated Assessment".

## THE MAPLIA SYSTEM

The MAPLIA system was designed to support the development of AQP requiring the definition and testing of local/regional abatement measures. It is based on a scenario analysis, which starts with the identification of control strategies/measures as a result of air quality exceedances. These measures have to be translated into emission reductions and their impacts on air quality quantified using modelling tools. Policy implications, technical feasibility, resulting costs and health impacts are evaluated, but not in a fully integrated perspective.

The MAPLIA system allows, therefore, evaluating the effects of previously selected measures in terms of costs, emissions, air quality, health impacts, and associated monetary benefits (i.e. avoided external costs). For this purpose, scenarios including different emission abatement measures are defined and their implementation costs are estimated. A reference scenario reflecting the emissions of a base year, for which only the influence of imposed/implemented measures in accordance with the legal framework is evaluated (CLE – Current Legislation Emissions), is the basis for the assessment. Reduction scenarios are established to cover non-compliance situations to the air quality limit values defined on the air quality Directive (2008/50/EC), aiming to act in an efficient and incisive way on the major emission sources in order to achieve significant benefits comparatively with the reference scenario. Based on the pre-defined emission scenarios, resulting emissions and air quality have to be quantified. The concentration values estimated by an air quality model, jointly with population data and morbidity and mortality indicators, expressed as health impact functions, allow calculating the number of attributable cases/days according to Equation 1. The number of cases is then transposed in monetary values allowing for the estimation of the avoided external costs per emission scenario. These costs are compared with the internal/implementation costs of the respective scenario (cost-benefit analysis), constituting an added value in the decision-making process to identify the best policies to adopt for air quality management.

The MAPLIA system was adapted to Portuguese needs and a set of input information was prepared, including: a detailed emission inventory, emission scenarios, reduction measures and related costs, population distribution by age, air pollution based health indicators, and source-receptor relationships.

## APPLICATION TO A CASE STUDY

The Grande Porto area (11 municipalities) was selected for the application of the MAPLIA system for the reference year 2012. This region of Portugal is one of the several EU zones that had to develop and implement air quality plans (AQP) to reduce PM10 and $NO_2$ concentrations (e.g. Miranda et al., 2015). This case study selection is based on the registered exceedances to the air quality limit values and on the available AQP. According to the national emission inventory, the share of NOx and PM10 emissions per activity sector for the Grande Porto area allows identifying industrial combustion, residential combustion and road traffic as the most relevant emission sectors.

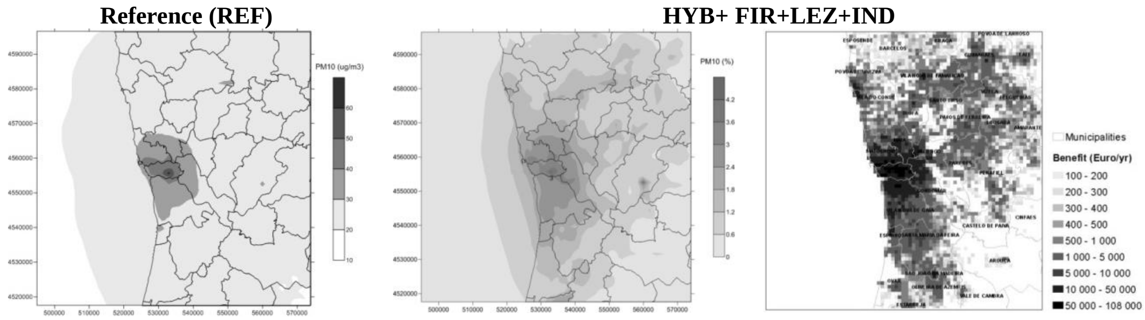
The MAPLIA application to Grande Porto consisted of an emissions, air quality, health and cost-benefit analysis for a set of 15 scenarios based on combinations of the following 4 emission reduction measures: 1) Replacing 10% of light vehicles below EURO3 by hybrids (HYB); 2) Introducing a Low Emission Zone in the Porto city banning vehicles below Euro 3 (LEZ); 3) Replacing/reconverting 50% of the conventional fireplaces by more efficient equipment (FIR); and 4) Application of particle reduction technologies allowing reducing 10% of PM10 emissions from industrial combustion and production processes (IND) (more details in Duque et al., 2016). These measures to reduce PM10 and $NO_2$ concentrations were characterized in terms of emissions, and their impacts on air quality were evaluated by the application of the TAPM (The Air Pollution Model) to the 15 scenarios defined, along the meteorological 2012 year conditions. The TAPM applied at 1km/1h horizontal and temporal resolutions allowed assessing air quality improvements based on the reference scenario, with no reduction measures.

Based on the achieved air quality state for the different reduction scenarios, human health impacts were quantified using the Equation 1. These impacts were analysed through morbidity and mortality indicators associated to PM10 and $NO_2$ concentrations due to short and long-term exposure. Additionally, for each health indicator a survey of the associated external costs per case/day was carried out. In terms of long-term exposure, the costs were expressed as annual average costs taking into account the duration and chronic effects of the disease. Table 1 gathers the information used in the reduction scenarios to estimate health impacts (ERF recommended in WHO, 2013) and subsequent external costs (Pervin et al., 2008) updated to the base year 2012.

**Table 1.** Input dataset used for quantifying health impacts and external costs assigned to the PM10 reduction scenarios.

| Health effect | Age group | Study design | Relative risk (%) | Baseline annual rate (%) | Cost (€) | Unit |
|---|---|---|---|---|---|---|
| Asthma | 5 - 19 yr | Short-term | 0.28 | 17 | 115 | Day |
| Heart failure | > 65 yr | Short-term | 1.85E-05 | Included in RR | 18,538 | Case |
| Chronic bronchitis (incidence) | >18 yr | Long-term | 1.17 | 0.39 | 18,970 | Year |
| Chronic bronchitis (prevalence) | 6-18 yr | Long-term | 0.8 | 18.6 | 18,970 | Year |
| Total mortality | < 1 yr | Long-term | 0.4 | 0.163 | 1,844 | YOLL |

Once determined the number of cases and known the annual costs per health indicator, the benefits (or avoided external costs) to human health resulting from the application of the reduction scenarios were estimated. There is a strong positive correlation between the spatial patterns of population density and health benefits associated to the reduction scenarios. It means, therefore, that in densely populated areas, normally with higher anthropic activity, and where the air pollution problems are more alarming, the potential health benefits of the reduction scenarios are larger than in rural areas. Furthermore, these abatement measures are focused on the main activity sources, mostly concentrated in urban centers, and so, air quality improvements in relation to the reference scenario are more significant on these air pollution hotspots. As an example, Figure 1 presents the spatial distribution of annual concentration averages (µg.m$^{-3}$) obtained for the reference case and for the scenario considering all emission reduction measures (in terms of percentage) and the human health benefits or avoided external costs (€.y$^{-1}$) for this total reduction scenario, for PM10.




(a) (b) (c)

**Figure 1.** Modelling results (annual averages): (a) PM10 concentration (µg.m$^{-3}$) for the REF scenario; (b) percentage reduction of PM10 concentrations between the REF and the scenario including all the reduction measures; (c) human health benefits (€.y$^{-1}$) for the total reduction scenario.

Model simulation results for the reference scenario showed higher annual averages (>30 µg.m$^{-3}$) over Porto and the surrounding area mainly, where concentrations exceeding the legislated limit values are expected (Figure 1a). The remaining domain is characterized by low annual concentrations (≅15-20 µg.m$^{-3}$). The largest reductions in PM10 annual concentration are obtained for the application of FIR and IND measures and a combination of them. More details can be found in Duque et al. (2016). The combination of all referred measures (HYB+FIR+LEZ+IND) indicates a total reduction of 4.5% in PM10 concentrations mainly over Porto, which corresponds to reductions of up to 2.8 µg.m$^{-3}$. The spatial pattern of the human health benefits (Figure 1c) shows that in densely populated areas the potential health benefits of the reduction scenarios are larger than in suburban/rural areas. The largest contribution for health benefits derives from the reduction in PM10 concentrations in the Grande Porto municipalities

The application of the MAPLIA system was completed with the balance between the internal/implementation costs and health benefits (or avoided external costs) allocated to each scenario, taking as basis the year 2012. Table 2 summarizes the estimated values (in M€.y$^{-1}$) of internal costs and external benefits, for the most relevant reduction scenarios tested and considering the aggregate effect of PM10 and NOx pollutants.

**Table2.** Cost-benefit analysis of the reduction scenarios.

| **Reduction scenario** | **Implementation costs** (M€.y$^{-1}$) | **Health benefits** (M€.y$^{-1}$) | **Net benefit** (M€.y$^{-1}$) | **Benefit-cost ratio (BCR)** |
|---|---|---|---|---|
| HYB | 2.0 | 1.5 | - 0.5 | 0.75 |
| FIR | 0.8 | 1.8 | 1.0 | 2.25 |
| LEZ | 3.8E-2 | 3.9E-2 | 1.0E-3 | 1.03 |
| IND | 5.8 | 5.6 | - 0.2 | 0.97 |
| HYB + FIR | 2.8 | 3.3 | 0.5 | 1.18 |
| FIR + IND | 6.5 | 7.4 | 0.9 | 1.14 |
| HYB+FIR+LEZ+IND | 8.6 | 8.9 | 0.3 | 1.03 |

The net benefit (i.e. benefits minus costs) per reduction scenario corresponds to the difference between the total health benefits (for NOx and PM10 and considering both short and long-term effects) and the implementation costs (in M €/year). Table 2 shows that the fireplaces' scenario (FIR) is probably the best strategic option to improve the air quality reducing negative impacts on health, as this abatement measure provides largest net benefits (1.0 M €/year) and with a benefit-cost ratio of 2.25. Furthermore, the significant influence of this scenario when combined with other measures is notable.

It should be mentioned that this cost-benefit analysis did not consider all air pollution related health impacts and associated benefits. Moreover, environmental impacts and benefits were also not taken into account in this analysis.

## CONCLUSIONS

An Integrated Assessment Modelling system specifically adapted to urban areas was developed (the MAPLIA system) following a scenario analysis approach and applied to a Portuguese urban region – Grande Porto Area. A group of 15 emission reduction scenarios was defined based on combinations of 4 emission reduction measures. All these scenarios were evaluated in terms of an emissions, air quality, health and cost-benefit analysis. Results revealed that, among the 15 scenarios analysed, the resulting scenario including all 4 measures lead to a total net benefit of 0.3 M€.$y^{-1}$. The largest benefit is obtained for the scenario considering the conversion of 50% of open wood stoves into heat recovery wood stoves. Although the implementation costs of this measure are high, the benefits outweigh the costs. The most cost-efficient scenario is the one that combines the heat recovery wood stove measure and the replacement of 10% of passenger cars below EURO 3 by hybrid vehicles.

The MAPLIA system is a useful tool for policy decision support for air quality improvement strategies, since it covers both air quality and health impacts and costs, and could be applied to other urban areas where AQP need to be implemented and monitored.

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## REFERENCES

Amann, M., Bertok, I., Borken-Kleefeld, J., Cofala, J., Heyes, C., et al., 2011: Cost-effective control of air quality and greenhouse gases in Europe: Modeling and policy applications. *Environ. Model. Softw.*, **26**, 1489-1501.

Carnevale, C., Finzi, G., Pisoni, E., Volta, M., Guariso, G., Gianfreda, R., Maffeis, G., Thunis, P., White, L., Triacchini, G., 2012: An integrated assessment tool to define effective air quality policies at regional scale. *Environ. Model. Softw.*, **38**, 306-315.

Duque, L., Relvas, H., Silveira, C., Ferreira, J., Monteiro, A., Gama, C., Rafael, S., Borrego, C., Miranda, A.I., 2016: Evaluating strategies to reduce urban air pollution. *Atmos. Environ.*, **127**, 196-204.

EC (European Commission), 2005: ExternE Externalities of Energy - Methodology 2005 Update, Office for Official Publications of the European Communities, Edited by Peter Bickel and Rainer Friedrich, EUR 21951 EN.

EEA (European Environment Agency), 2015: Air quality in Europe - 2015 Report, EEA Report. No.5/2015, Copenhagen, ISSN 1977-8449, 64 pp.

Miranda, A.I., Silveira, C., Ferreira, J., Monteiro, A., Lopes, D., Relvas, H., Borrego, C., Roebeling P., 2015: Current air quality plans in Europe designed to support air quality management policies. *Atmos. Pollut. Res.*, **6**, 434-443.

O'Connell E. and Hurley F., 2009: A review of the strengths and weaknesses of quantitative methods used in health impact assessment. *Public Health,* **123**, 306-310.

Pervin, T., Gerdtham, Ulf-G, Lyttkens, C.H., 2008: Societal costs of air pollution-related health hazards: A review of methods and results. *Cost. Eff. Resour. Alloc.*, **6**, 22 pp.
Smith, K.R., Corvalán, C.F., Kjellström, T., 1999: How much global ill health is attributable to environmental factors? *Epidemiology*, **10**, 573-584.
WHO, 2013: Recommendations for concentration–response functions for cost–benefit analysis of particulate matter, ozone and nitrogen dioxide. Health risks of air pollution in Europe – HRAPIE project, WHO Regional Office for Europe, Copenhagen, Denmark, 54 pp.