A versatile decision-support tool to assess air quality and health effects

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Abstract

This work presents a web-based policy tool for the development of effective particulate matter (PM) pollution strategies. The tool is based on an integrated modelling approach, from emissions to health effects, which allows testing measures to improve air quality, focused on PM2.5 levels, and quantitatively assess their impact on the health and well-being of the populations. The tool was developed in the framework of the LIFE Index-Air project and this work describes its particular application to Athens (Greece) simulating the effect of two air quality improvements measures on the PM2.5 levels. The application of the tool for the reference scenario indicates that Athens did not comply with the European air quality standards (25 µg.m^{-3}) for the annual PM2.5 levels in 5% of the simulation domain. Two mitigation measures were simulated: i) fireplace improvement, and (ii) introduction of passenger electric vehicles. The results show that, in Athens, the electrification of the fleet is more effective, allowing to reduce up to 3 µg.m^{-3} on the annual average of PM2.5 concentrations. The tool allows for rapid exploration of potential air quality and health improvements resulting from different control measures, supporting stakeholders in decision-making.

Keywords: Air quality modelling, Artificial Neural Networks, Integrated Assessment Model, PM2.5, Athens

1. Introduction

Urbanization is still a leading trend with more than half of the world's population living in cities and that projection expected to increase (United Nations, 2019). Therefore, citizens are an important element of future sustainability, health, and wellbeing. Some of the most important health challenges in this urban environment are related to air pollution, noise, lack of green space, inadequate transport, as well as reduced opportunities for physical activities. In 2019, air pollution was considered by the World Health Organization (WHO) as the greatest environmental risk to human health. About 49% of the cities in high-income countries with more than 100K inhabitants do not meet air quality guidelines (WHO, 2019). The leading health outcome attributed to air pollution is cardiopulmonary effects, including respiratory infections, cardiovascular diseases, and lung cancer (Manisalidis et al., 2020).

To choose the best measures to be applied to ensure healthy air, decision-makers need fast decision support tools. The ongoing project LIFE Index-Air developed an inventive and flexible decision support tool for policy agents, based on an Integrated Assessment Modelling (IAM) approach (Miranda et al., 2016), going from the emissions until the health effects.

The main objectives of this paper are: (i) to present the core methodology used in the development of the LIFE Index-Air tool, (ii) to apply the developed methodology by testing the effect of two air quality mitigation measures in Athens (Greece).

2. Methodology

The LIFE Index-Air tool is based on an integrated assessment that includes data on major emission sources, PM concentrations, time-activity patterns of different population subgroups and several dedicated models providing the following datasets:
(1) Spatial distribution (1 km × 1 km resolution) of annual ambient PM10, PM2.5 and Ni, As, Cd, and Pb concentration levels;
(2) Human exposure levels for different population subgroups, as well as for total city population;
(3) Dose of PM10, PM2.5 and PM2.5-10 deposited in the respiratory system, during exposure in different microenvironments and under specific anatomical and

physiological conditions determined by a subject's age and activity;
(4) Health indicators, namely Disability-Adjusted Life Year (DALY), Years of Life Lost (YLL), Years Lost due to Disability (YLD), and number of Deaths, due to exposure to PM2.5, based on Burden of Disease (BoD) methodology.
(5) Impacts of applying improvement measures.
The estimation of impacts is based on a scenario building module.

To estimate the air quality levels and the impact of air pollution mitigation strategies, Chemical Transport Models (CTM) are widely used. However, air quality modelling simulations employing CTM cannot directly be used inside the Life Index-Air management tool to simulate the link between precursor emissions and air quality indexes due to their computational and time requirements. For that reason, a computationally efficient Artificial Neural Networks (ANN) previously trained with a set of ten full-year CTM simulations was used to assess the impact of emission reduction measures on air quality.

The air quality modelling system is composed of the Weather Research & Forecasting (WRF-ARW, version 3.7.1) (Skamarock et al., 2008) and the Comprehensive Air Quality Model with Extensions (CAMx, version 6.40) (ENVIRON, 2015). The WRF-CAMx air quality modelling system was selected to be applied under the Index-Air project according to its suitability to simulate the meteorological conditions and the atmospheric concentrations of particulate pollutants for the study regions. More details about the modelling setup can be found in (Ferreira et al., 2020; Korhonen et al., 2021).

The selected ANN structure considers input coming from four contiguous quadrants, thus considering prevalent wind directions (Relvas et al., 2017). It was considered a radius of influence of the emissions (number of cells) of 4. Then, the surrogate model was trained and validated using the Levenberg–Marquardt algorithm. The best result was achieved considering two hidden layers with 30 neurons each and a log-sigmoid transfer function. Figure 5 presents the validation results for the $PM_{2.5}$ neural network model based on a scatter plot that compares the WRF-CAMx output results with the ANN outputs.

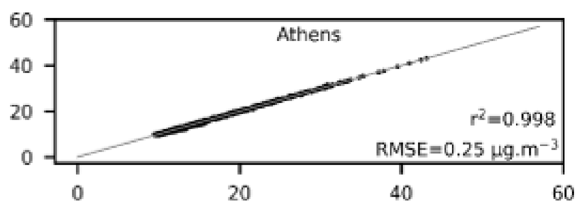


Figure 1. Surrogate model validation scatter plot between WRF-CAMx (x-axis) and ANN (y-axis) for PM2.5 yearly average concentration (b).

Figure 1 also includes the root-mean-square error (RMSE), which gives important information about the skill in predicting the magnitude of a variable allowing to diagnose the variation in the errors in a set of predicted values, and the coefficient of determination (r2), which indicates the strength of the relationship between variables. The high obtained r^2 values and the low RMSE highlight the good fit between both approaches (CTM and ANN). An increased number of scenarios can potentially improve the obtained results, including ANN generalization capability. More details about the methodology applied to train the ANN can be found in (Relvas et al., 2017; Relvas and Miranda, 2018).

The LIFE Index-Air tool was applied to Athens aiming to evaluate the effect of two air pollution mitigation measures in the PM2.5 concentration levels.

3. Application to Athens

Anthropogenic emissions were taken from the European emission inventory based on Member States submissions for the year 2015. The EMEP inventory, with a horizontal resolution of 0.1° (approximately 10 km), comprising annual emission totals by activity sector for gases and particulate species including metals, was disaggregated to the case study modelling domain. In order to improve the spatial resolution of the emission inventory, the emissions were spatially disaggregated to 1 km resolution considering different proxies.
For the simulation domain it was estimated approximately 95 kt/year of PM2.5. Figure 2 displays the share of the emission by SNAP (Selected Nomenclature for Air Pollution) emission activities.

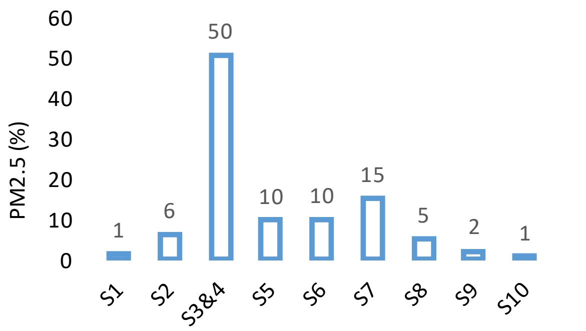


Figure 2. Emissions share of PM2.5 for Athens domain for the following SNAP activities: SNAP1 – energy production, SNAP2 – commercial, services and residential combustion, SNAP3&4 – industrial combustion and production processes, SNAP5- extraction and distribution of fossil fuels, SNAP6 - solvents use, SNAP7 - road transport, SNAP8 – maritime transport, aviation and off-road transport, SNAP9 - waste treatment and disposal, and SNAP10 – agriculture.

Then the WRF-CAMx modelling system was applied and validated using data from existing monitoring air quality stations in the domain. The modelling setup shows a good ability to simulate the spatial pattern of PM2.5 over Athens as depicted by the air quality monitoring measurements represented by small circles in Figure 2, which displays the spatial distribution of annual PM2.5 simulated by the WRF-CAMx modelling system.

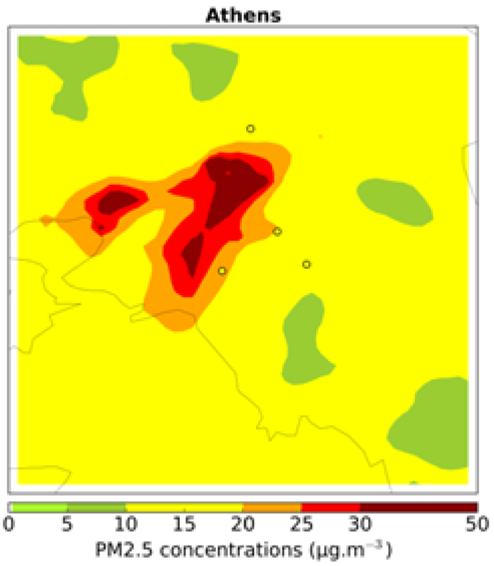


Figure 3. Annual average concentrations of PM2.5 levels for Athens (Greece) in 2015. The annual averages measured in the European air quality monitoring network are represented by small coloured circles.

Athens did not comply with the European air quality standard (25 µg.m^{-3}) for the annual PM2.5 levels over an area of 5% of the simulation domain. The spatial average of annual PM2.5 concentrations was 14 µg.m^{-3}, with a maximum value of 40 µg.m^{-3}.
To test the developed tool, two mitigation measures were considered: i) improvement of the biomass residential combustion appliances; and ii) electrification of passenger's cars fleet. The residential heating scenario (SNAP2) considers the total replacement of conventional residential fireplaces (Open Fireplaces), Woodstoves, and Salamander Stoves by more efficient equipment, namely More Efficient Fireplaces The road traffic scenario (SNAP7) considers the replacement of all petrol and diesel passenger vehicles by electric ones. Figure 4 presents the map of the PM2.5 concentration difference between the reference case and the traffic scenario. While Figure 5 presents the reduction achieved on the municipality of Athens (city center).

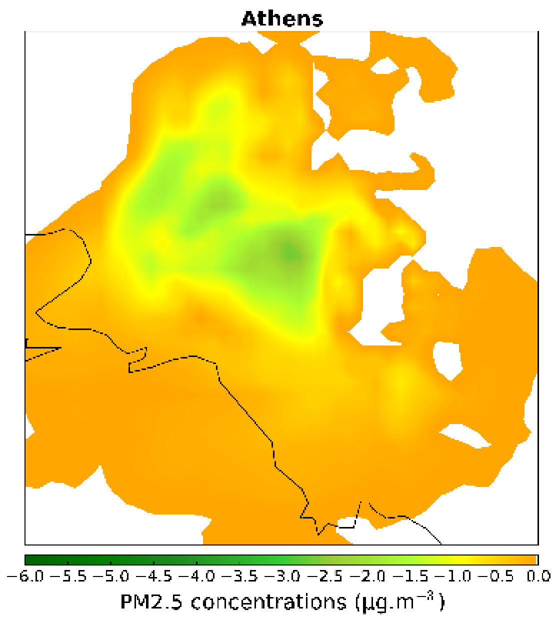
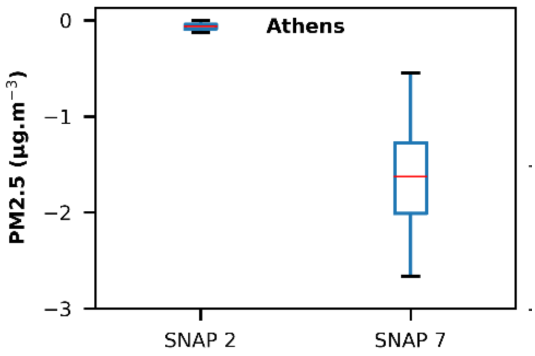


Figure 4 - PM2.5 concentration differences between the



reference case and the traffic electric scenario, for the Athens domain.
Figure 5. Reduction of PM2.5 concentrations over Athens municipality, considering the two scenarios. The Red line represents the mean, boxes the 25th and 75th quartiles while the whiskers show the maximum value of 95th percentile and minimum value of 5th percentile.

The results point out that in Athens municipalities the electrification of passenger fleet is quite effective, with an average reduction of 1.5 µg.m^{-3} but achieving reductions higher than 3 µg.m^{-3} in the city centre. The residential heating scenario is not efficient in deducing PM2.5 in Athens domain and especially in the municipality of Athens.

4. Conclusions

The LIFE Index-Air management tool was developed in the framework of the LIFE Index-Air project (LIFE15 ENV/PT/000674) aiming to cover the gap between ambient air quality management and real-life exposure of urban populations and related health risks. It aspires to provide policymakers with the means to assess citizens' exposure to PM and related health effects, as well as to evaluate the effectiveness of selected air pollution mitigation measures concerning ambient air quality, population exposure and the protection of public health. The tool also aims to enhance the knowledge of the general public on PM pollution, its sources, means of exposure and health effects and to raise awareness regarding the adoption of sustainable and environmentally friendly practices in our everyday lives.

The application of the tool to Athens indicates that the replacement of gasoline and diesel passenger vehicles by electric vehicles seems to be more effective than the replacement of conventional residential fireplaces in reducing the PM2.5 concentrations over the city. To boost the air quality improvement, in addition to passenger vehicles electrification, the electrification of light-duty vehicles, heavy-duty vehicles and buses is strongly recommended.

Future work will include the application of the LIFE Index-Air tool with its other modules (Exposure, Dosimetry and Burden of Disease) to estimate the health benefits related to these measures over the city of Athens.

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