International Environmental Modelling and Software Society (iEMSs)
7th Intl. Congress on Env. Modelling and Software, San Diego, CA, USA,
Daniel P. Ames, Nigel W.T. Quinn and Andrea E. Rizzoli (Eds.)
http://www.iemss.org/society/index.php/iemss-2014-proceedings

Development of a Policy Tool towards Particulate Pollution Abatement

Athena G. Progiou[1], Ioannis C. Ziomas[2],
Nickolaos M. Panagiotou[2], Christos J. Boukouvalas[2]
[1] AXON Enviro-Group Ltd, 18 Troias str., 11257 Athens, Greece, ap@axonenviro.gr
[2] Laboratory of Process Analysis and Design, School of Chemical Engineering, National Technical University of Athens, 9 Heroon Polytehneiou str., Zografou Campus, 15780 Athens, Greece
ziomas@chemeng.ntua.gr, nickpan@chemeng.ntua.gr, bouk@chemeng.ntua.gr

Abstract: Particulate matter concentrations are in most cities a major environmental problem. This is also the case in Greece where, despite the various measures taken in the past, the problem still persists. In this aspect, in the framework of the European Life Programme ACEPTAIR, a cost efficient, comprehensive policy tool was developed in order to help decision makers to take the most appropriate measures towards particulates pollution abatement. In the framework of the project, the tool was applied for the areas of three major Greek cities. The operational platform consists of two modules, a database and an algorithm for the calculation of particulate levels for different emissions scenaria. The database comprises historical measurements data, the corresponding emissions data from all sources as well as source apportionment data. In the second module, the algorithm can be applied in order to forecast particulate levels taking into account various reduction measures or the business as usual scenario. The tool can be used for future or past conditions giving thus the possibility to the decision makers to evaluate ex ante or ex post the effectiveness of specific abatement measures. Moreover, the ex post evaluation is useful for testing and validation reasons. Finally, the tool is user friendly and it can be easily updated when new input data are available.

Keywords*: policy tool; particulates concentrations; air pollution; emission sources; decision making*.

1 INTRODUCTION

In the last decades, all major Greek urban areas, among many other European urban agglomerations, face atmospheric pollution problems mainly associated with high levels of particulates, nitrogen dioxide and ozone. Particulate matter (PM) includes condensed phase particles suspended in the atmosphere, ranging in size from nanometres to several hundred micrometres and deriving from both anthropogenic and natural sources or formed by the reaction of atmospheric gases. These airborne particles are a major environmental problem as new evidence regarding their harmful impact on human health has emerged. Moreover, recent research results pointed towards the smaller particles as mostly responsible for health hazards like premature mortality, hospital admissions, allergic reactions, lung dysfunction and cardiovascular diseases. (Harrison et al., 2010; Restrepo et al., 2012).

At present, in Greece, emissions as well as concentration levels generally show a decreasing trend (Progiou and Ziomas 2011a, 2011b), as a result of a number of measures adopted in the last two decades towards emissions reduction. Such measures included a withdrawal programme of older technology vehicles along with a tax reduction programme for the purchase of new anti-polluting technology vehicles as well as the adoption of Best Available Techniques (BATs) in the industrial sector. Despite the measures taken and the ambient PM levels decrease, exceeding of airborne particulates still occur. The quantitative result of the effect of the measures taken, with respect to each one of the emission sources, is largely unknown. Although a lot of research was carried out to investigate the existence of a direct relationship linking air quality levels and air pollution emissions from transportation in several urban agglomerations (Borrego et al., 2000; Kassomenos et al., 2004; Kassomenos et al., 2006; Progiou and Ziomas 2011b; Zamboni et al., 2009), it seems that other emission sources contribute significantly to high PM levels and, hence, their contribution should be also investigated and quantified. Moreover, as the European Union (E.U.) is moving towards the implementation of a new thematic strategy on air pollution, requirements of lower limit values for PM levels in the atmosphere will come in effect. As a consequence, emissions reductions will become obligatory and all abatement measures to be applied should be examined on a cost effective basis and assessed for their results. This is a main problem stakeholders from national and local governments are facing.

In this sense the National Centre of Scientific Research “Demokritos”, Aristotle University of Thessaloniki, University of Thessaly, Technical University of Crete and AXON Enviro-Group Ltd. along with the participation of the Direction of Atmospheric Pollution and Noise Control of the Ministry of Environment, Energy and Climate Change and the corresponding Direction of Environment of the Regional Administration of Thessaloniki and Volos have submitted a proposal to the European Community LIFE + Environment Policy and Governance Programme.

The present work was carried out in the framework of the European Life + Programme ACEPTAIR (*www.aceptair.prd.uth.gr*). The project is targeting, firstly, to unravel the relative contribution of the multiple anthropogenic and other sources to the observed PM air concentrations. Secondly it documents the relative contribution of secondary aerosol particles to those from primary emissions, by taking into account the atmospheric processes which contribute secondary and primary PM at any given receptor site.

2 AIM AND METHODOLOGY

As already mentioned, the potential of PM for causing health problems is directly linked to the size of the particles. Particles with a diameter less than 10 micrometers (PM_{10}) pose a health concern because they can be inhaled into and accumulate in the respiratory system. Particles with a diameter less than 2.5 micrometers ($PM_{2.5}$) are referred to as "fine" particles and are believed to pose the greatest health risks. As a result of their small size (approximately 1/30th the average width of a human hair), fine particles can lodge deeply into the lungs.

In this context, the main aim of this work was to provide the competent authorities at central regional and local level with a useful tool to control $PM_{2.5}$ and PM_{10} concentrations. The areas of study are the Metropolitan Area of Athens, the Metropolitan Area of Thessaloniki and the Metropolitan Area of Volos. Athens, as the capital, is the largest Greek city with about 4.5 million inhabitants, Thessaloniki is the second largest city with 1 million inhabitants and Volos is a smaller city with about 90,000 inhabitants. All three cities face pollution problems with high PM levels.

One of the main concerns in the course of this job was to develop a user friendly, easily applied tool so as not to surpass the skills and expertise of the stakeholders involved. To this end, during the design phase, all stakeholders were asked to answer a questionnaire. Furthermore they have participated in consecutive meetings regarding the development of the operational platform and discussed in full detail the functions of the tool. During this procedure, a draft version of the tool was distributed in order to have the stakeholders’ feedback.

The key issues revealed from this interactive process regarding the function of the tool stressed the need for an up-to-date emissions inventory database from all sources and the importance to quantify the contribution of each emission source to the concentration levels occurred taking into account anthropogenic as well as natural emission sources for the three cities. As a conclusion, a dynamic tool combining the above along with the possibility to assess and quantify the results of various abatement measures in ambient PM levels would be the final goal.

As from the above, the decision making tool aims at:

a) The complete overview of the currently PM measured concentrations and calculated emissions in selected Greek regions, making available the disaggregation of data at a sectoral level.
b) The estimation and direct presentation of the effects of specific interventions on the overall sectoral structure of PM concentrations in Greek urban areas, based on the performed measurements.
c) The quantitative determination of the weighed contribution of anthropogenic versus natural emissions.

d) The establishment of organized databases for anthropogenic emission source strength and the naturally emitted material primary and secondary, originating from local or distant sources.
e) Assisting National and Regional authorities to implement the "Thematic strategy on Air Pollution" which is regarded as an action of high priority for member states.
f) Allowing the adoption and evaluation of control strategies capable of underpinning sustainable development despite expected changes in emissions from new materials, changes in the energy and fuel supply sectors as well as anticipation of climate change and long term changes in the atmosphere.
g) The access of relative information described in scientific papers and other material published in the international press.

According to the above, the software application was created encompassing the following axes given below:
a) ***Data collection*** filtered by quality assurance and quality control procedures (QA/QC) and creation of parameter databases that will be used to calculate future PM levels. Main datasets include PM_{10} and $PM_{2.5}$ measurements and air pollutants emissions.
b) ***Processing and analysis of the input data*** (concentration measurements and emissions calculations)
c) ***Source apportionment analytical package (receptor model).*** In general, the chemical composition and size distribution of particulate matter are characteristic for each emission source. The identification and quantification protocol followed to specify the contribution of each emission source to PM levels is described as receptor model. In this tool the two receptor models most commonly used in Europe and United States, the Positive Matrix Factorisation (PMF) and the Chemical Mass Balance (CMB), were employed (Samara 2005, Karanasiou et al, 2009).
d) ***Data trend and objective analysis*** are applied on the results of emission source strengths obtained from emission data and relative contributions calculated by receptor modeling.
e) ***Development of PM levels forecasting equation.*** The equation developed combines calculated air pollutant emissions, PM concentrations measurements and source apportionment data. The results from new emission control strategies, the application of green measures and new products can all be evaluated by the policy tool developed, with respect to the measured reduction in PM concentration taking into account all emission sources.
f) ***Quantitative projections of future PM levels*** with respect to adopted measures.

It is to be stressed that the outcome of all the above functions and results composes a critical tool in order the country to comply with the requirements of the Directive 2008/50/EC.

3 DESCRIPTION

In the framework of the Policy Tool development, state of the art data and models results were incorporated, combining comparative analysis of source contributions as resulted from air concentrations and emission inventories. The tool possesses a historical record of emissions changes, targeted or economy driven, and provides results in measured concentration reductions apportioned to changes in every accounted source. This can allow the policy makers to evaluate quantitatively the effects of control measures and policies on specific sources.

The construction of the emissions inventories along with the source apportionment model (receptor model) results and the measurement data in the three areas are prerequisites in order to associate emission trends and changes from different emission sources with the corresponding particulates concentrations. Consequently, the kind of the measures to be taken can be determined and the anticipated effects of the measures proposed can be quantified. In this paper only the operational platform developed will be described. The emissions inventories development along with the source apportionment results will be presented elsewhere.

An Operational Platform (OP) for analysis of the results, facilitating the assessment of the relative trends in emissions and observed concentration levels in parallel to the resolved contributions from the different emission sources was implemented. The Operational Platform comprises a database application, developed in accordance with the methodology applied and the parameters selected. The database contains field measurement data, historical measurement data as well as emissions inventories data along with source apportionment assessments by means of suitable models. Data from the existing PM monitoring network are integrated in the Operational Platform on an annual basis since these data are used for trend analysis and not for the source apportionment procedure. In other words, PM monitoring quantifies the observed result of emission and other changes over the years. The database is an integrated information resource, which stores all data and meta-data collected and produced. These data, along with other historical data, are held in standardised structures in order to support the cross-disciplinary analyses necessary.

From a programmer's point of view the structure of the tool comprises of three interconnected yet clearly separated parts ('3-tier approach'):

- the Database and programming related to manage it
- the Business Logic ('Business Tier') that includes the code referring to the update and calculations to be performed
- the Presentation Interface

As it is shown in figure 1, the tool functions are divided into three categories:

- **Data presentation** where the data stored (emissions, graphics, publications etc) can be presented in various ways
- **Scenarios Build-up** where the emissions data stored can be processed taking into account future emission scenarios in order to forecast potential future concentrations changes/trends
- **Database** where the tool databases can be accessed in order to be seen, updated, removed or in order to add new data

An example of concentration data for the whole time series are presented in figure 2, whereas an example of emissions from all anthropogenic and natural sources is presented in figures 3 and 4. Concentration data include not only PM but other pollutants too as CO, NOx, NMVOCs, SO2 and NH3, as these pollutants play an important role in air pollution levels and some of them contribute significantly to the secondary aerosol formation which is an important PM source.

Figure 1. Main Menu and Data Presentation.

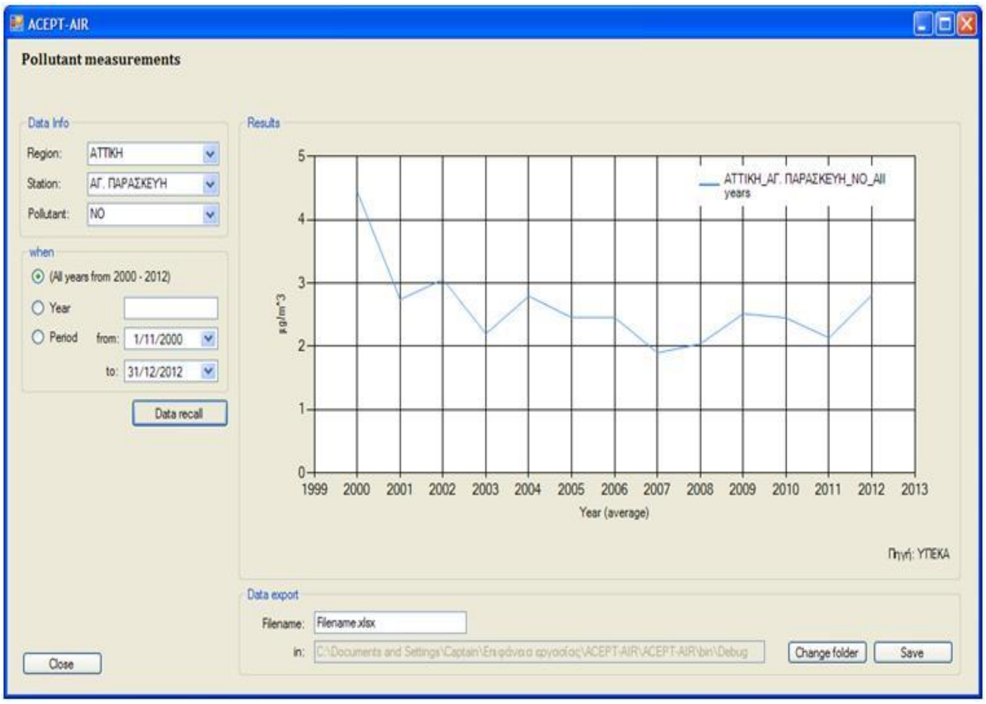

Figure 2. Presentation of long term trend of concentration data.

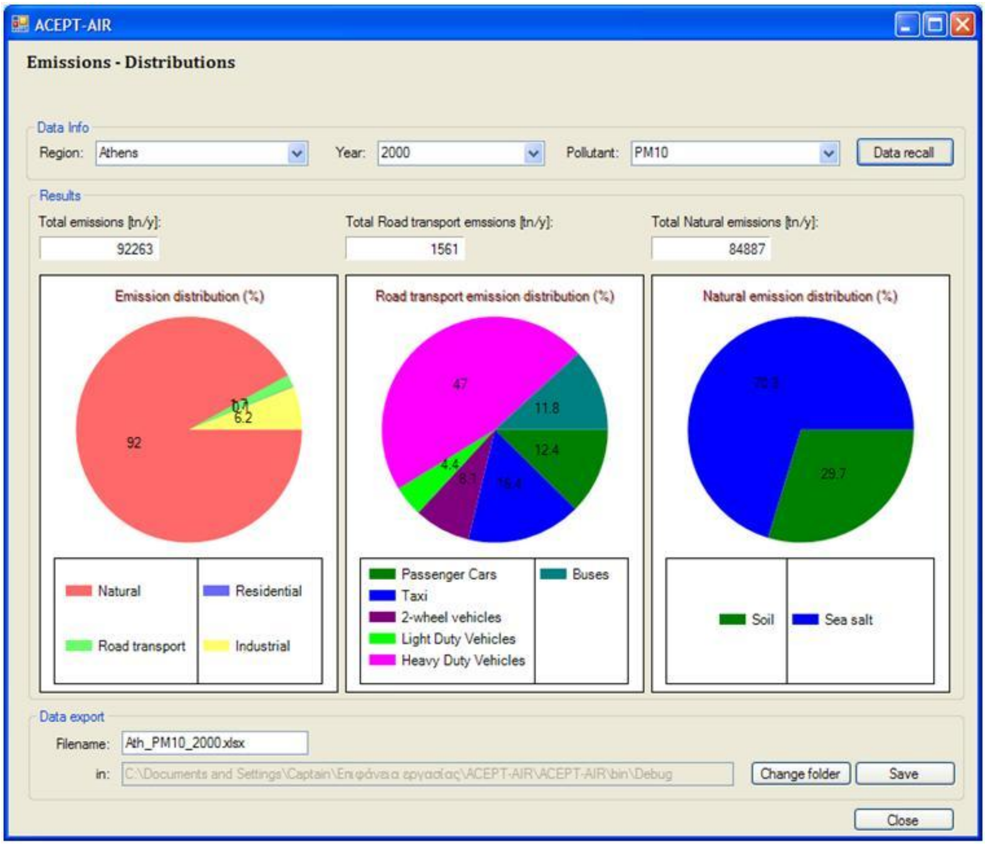

Figure 3. Schematic presentation of emission sources and sub-sources.

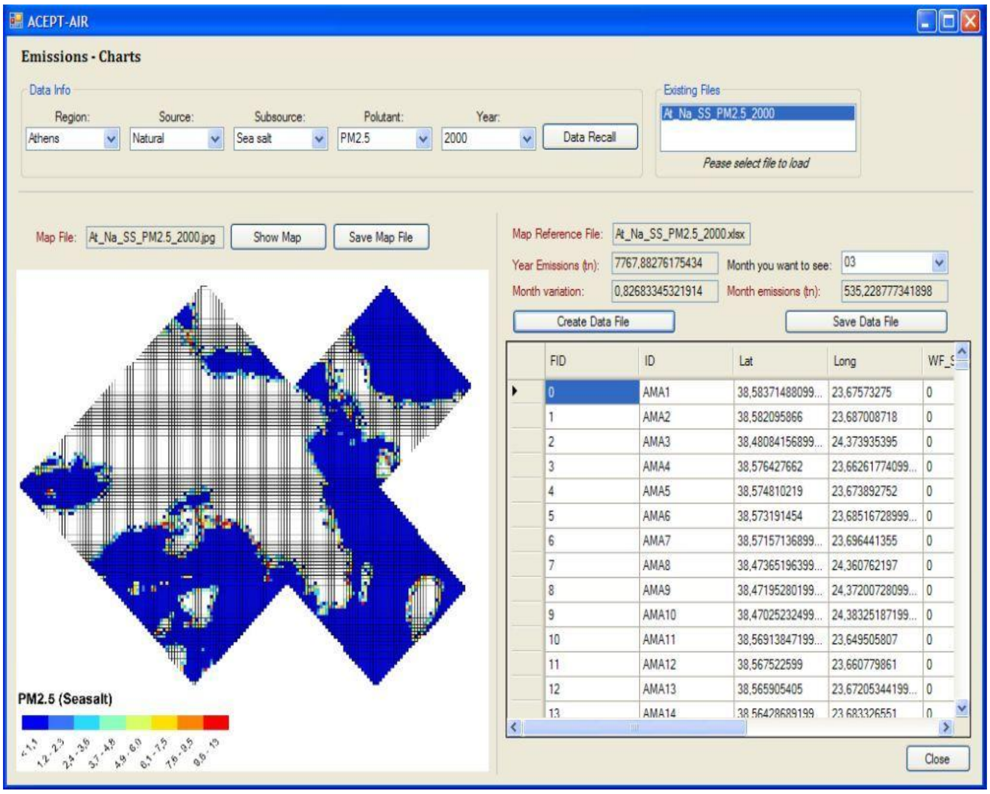

Figure 4. Spatial allocation of natural $PM_{2.5}$ emissions.

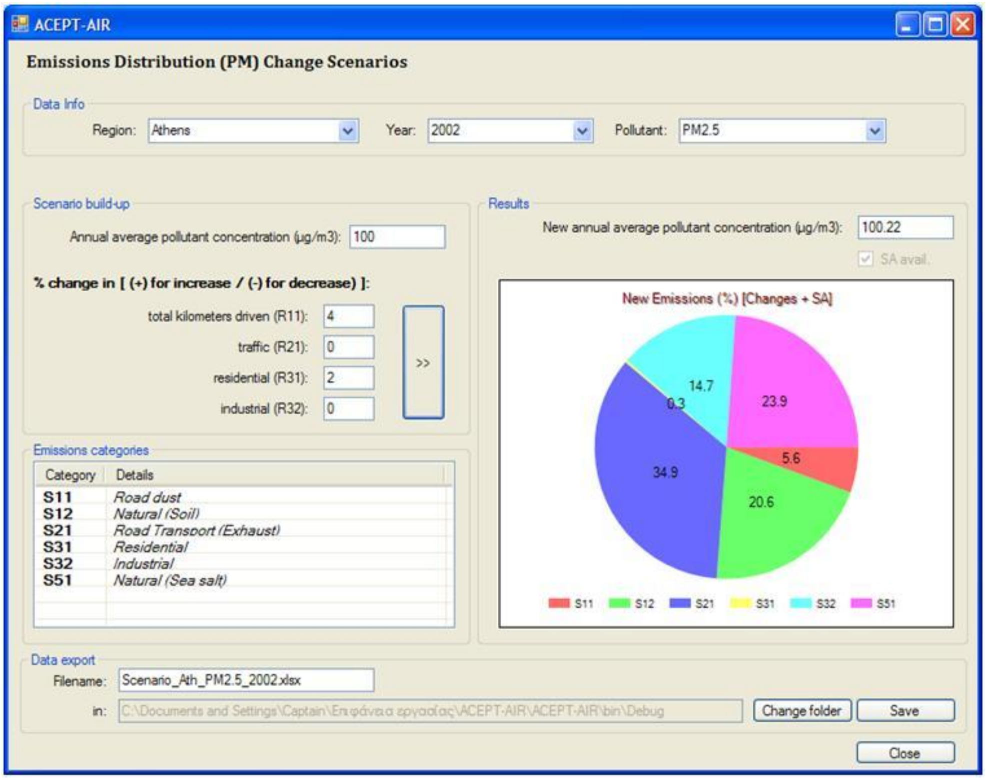

Figure 5. Setting measures to reduce PM concentrations.

Emissions data include emissions from anthropogenic sources such as road traffic, industry, residential heating and commercial activities, as well as from natural sources (soil dust and sea salt). Finally, source apportionment data are presented for all regions and for all years with data available.

It should be noted, that except from exhaust emissions, PM emissions related to tyre and break wear as well as road surface wear are taken into account.

In the Scenario build up section, the input parameters required are the initial average concentration and the anticipated changes of emissions as a result of measures taken, as well as the new average PM concentration. The equation applied to calculate the new PM concentration is the following:

$$C_{new}=C_{old}*(1+\sum_{i=1,n}(\Delta PEi * SAi)+\sum_{j=1,k}(\Delta PEj * SEj)) \quad (1)$$

Where:

C_{new} is the resulting concentration after the application of particulate pollution abatement measures
C_{old} is the initial concentration (of the current or earlier years)
PEi is the primary PM emission of source i and *ΔPEi* is the estimated reduction/increase of the corresponding emission source
SAi is the contribution of emission source i to the PM levels occurred
PEj is the emission source j related to secondary aerosol production and *ΔPEj* is the estimated reduction/increase of the corresponding emission source
SEj is the contribution of emission source j to the PM levels occurred

In this section, the user has the possibility to quantify the impact on air quality of measures leading to emission changes. For example, given that the user knows the contribution of each vehicle category to total road traffic emissions from the emissions inventories, through the source apportionment data, he is able to propose measures concerning specific vehicle categories. Based on the above, the tool provides the user with the quantified result of the policy measures applied, in other words the new PM concentration. In figure 5, an example of the tool prediction is provided. Finally, in the Database section, the user can add or remove data and backup or restore the database. The new data should be added in the same simple excel format as the existing data files. The new data concern measurements, emissions, source apportionment data as well as new publications in the field. In the tool menu specific options exist that provide the user with the possibility to see, add, remove or restore all relevant data.

4 CONCLUSIONS

In the last decades, all major Greek urban areas, among many other European urban agglomerations, face atmospheric pollution problems mainly associated with high levels of particulates, nitrogen dioxide and ozone. As the E.U. is moving towards lower limit values for PM levels in the atmosphere, reduction in emissions will be required and abatement measures effects should be pre-assessed and quantified.

The present work is targeting to unravel the relative contribution of the multiple anthropogenic and natural sources to the observed PM air concentrations as well as to document the relative contribution of secondary aerosol particles to those from primary emissions. Primarily this work aims at providing the competent authorities at central regional and local level with a user friendly tool to control $PM_{2.5}$ and PM_{10} concentrations in air. The results from new emission control strategies, the application of green measures and new products can all be evaluated by the policy tool developed, with respect to the measured reduction in PM concentration taking into account all emission sources.

Main advantages of the decision making tool are its user-friendliness and its fast response in quantifying anticipated effects of specific measures. Moreover it possesses an easily manageable database with options to backup, restore, update and add or remove data. Thus, the tool can be applied in the long run, given that the user updates pollutants emissions and concentrations. This is feasible, as input data concerning anthropogenic sources can be derived from existing national inventories. Source apportionment data have a longer life period, as they are in general valid, in the business as usual scenario, for several years. Finally, the various functions of the tool provide a thorough image of all environmental parameters, like concentrations measurements and emissions, in the area of interest.

Future plans for the policy tool further development include improvements in emission inventories, especially from industrial sources, and source apportionment data.

ACKNOWLEDGMENTS

This work is supported by the European Commission LIFE+ Environment Policy and Governance Programme and was developed in the framework of the LIFE+ project ACEPT-AIR.

REFERENCES

Borrego C., Tchepel O., Barros N., Miranda A.I., 2000. Impact of road traffic emissions on air quality of the Lisbon region. Atmos Environ 34, 4683-90.

European Life + Programme ACEPTAIR, 2014, http://www.aceptair.prd.uth.gr.

Harrison R.M., Giorio C., Beddows D.C., and Dall'Osto M., 2010. Size distribution of airborne particles controls outcomes of epidemiological studies. Sci. Total Environ., 409, 289-293.

Progiou A., Ziomas I., 2011a. Twenty-Year Road Traffic EmissionsTrend in Greece. Water Air Soil Pollut, DOI 10.1007/s11270-011-0859-9.

Progiou A.G., Ziomas I.C.. 2011b. Road traffic emissions impact on air quality of the Greater Athens Area based on a 20 year emissions inventory, Science of the Total Environment 410, 1–7.

Restrepo C. E., Simonoff J.S., Thurston G.D., Zimmerman R., 2012. Asthma Hospital Admissions and Ambient Air Pollutant Concentrations in New York City. Journal of Environmental Protection, 3, 1102-1116.

Karanasiou A.A., Siskos P.A., Eleftheriadis K., 2009. Assessment of source apportionment by Positive Matrix Factorization analysis on fine and coarse urban aerosol size fractions. Atmos. Environ., Vol 43, pp 3385-3395.

Kassomenos P., Karakitsios S., Pilidis G., 2004. A simple semi-empirical approach to modeling benzene concentrations in a street canyon. Atmos Environ, 38, 6073-6078.

Kassomenos P., Karakitsios S., Papaloukas C., 2006. Estimation of daily traffic emissions in a South-European urban agglomeration during a workday. Evaluation of several "what if" scenarios. Science of the Total Environment, 370, 480–490.

Samara C., 2005. Chemical mass balance source apportionment of TSP in a lignite-burning area of western Macedonia, Greece. Atmospheric Environment 39, 6430–6443.

Zamboni G., Capobianco M., Daminelli E., 2009. Estimation of road vehicle exhaust emissions from 1992 to 2010 and comparison with air quality measurements in Genoa, Italy. Atmos Environ, 43, 1086-92.