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THE ROLE OF AIR QUALITY MODELLING IN PARTICULATE MATTER MANAGEMENT IN CITIES. RESULTS FROM THE AIR IMPLEMENTATION PILOT

Article Highlights

- Better understanding of the challenges faced by cities in implementing air quality policy
- Type of models used for air quality assessment and management
- Lessons learned in the implementation of air quality legislation

Abstract

The European Commission and the EEA agreed to reinforce efforts to improve knowledge on implementation of air quality legislation through a joint pilot project. The Air Implementation Pilot run from March 2012 to June 2013 and aimed at better understanding the challenges cities faced in implementing air quality policy. Twelve European cities were selected and invited to join the project. One of the aims of the Pilot project was to assess the use of models for air quality assessment and management, share experiences, and identify needs for further guidance. The results of the analysis of modelling practices are presented in this work. More than 20 different models have been used for air quality assessment and management in these cities. The main purposes for which cities applied models are air quality assessment, quantification of source contribution and long term planning. The cities have found models helpful and the outputs have been used in urban air quality assessment and management, including the evaluation of strategies to reduce PM ambient levels. However, the cities found difficulties in the application of models as for instance the quality and availability of input data or the validation and uncertainty estimation of the model results.

Keywords: air quality models, urban air quality management, particulate matter, EU legislation.

The quality of the environment in urban areas is of vital importance and it is one of the main factors that determine whether a city is a healthy place to live in. Europe is one of the most urbanized continents in the world. Today, more than two thirds of the European population lives in urban areas and this share continues to grow [1]. At the same time, car use in Europe is growing and a further doubling of traffic is predicted by 2025 [2]. Traffic is the dominant urban air pollution source per today along with domestic combustion (which has been growing over the last few years) [3]. Persistent air quality exceedances of the limit or target values for particulate matter are observed in urban areas across Europe [4]. Furthermore, in 2011 33% of the urban population in Europe was exposed to concentrations of PM_{10} in excess of the EU daily limit value and 15% was exposed to $PM_{2.5}$ concentrations above the EU target value [3].

In 2011, the European Commission and the European Environment Agency (EEA) agreed to reinforce efforts to improve knowledge on implementation of air quality legislation through a joint pilot project [5]. The objective of the pilot was to help identifying and addressing the reasons underlying why some pollutants concentrations remain above regulated levels, and find “effective ways of dealing with problems on the ground” that prevent the effective implementation of environmental legislation. The Air Implementation

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Pilot aimed to better understand the challenges cities faced in implementing air quality policy, identify good practices, encourage cities to share their knowledge and experiences, so they could learn from each other, and identify areas where further guidance would be helpful. The Pilot brought together 12 cities across the European Union and was jointly run by the cities themselves, the European Commission, and the European Environment Agency [5].

The Air Implementation Pilot project lasted for 15 months, starting in March 2012. The cities selected to join the pilot are a representative sample of the diversity of European urban areas. The selection aimed at including cities from different parts of Europe, of different population sizes, with different administrative traditions, and with a variety of sources of air pollutants. The cities are: Antwerp (Belgium), Berlin (Germany), Dublin (Ireland), Madrid (Spain), Malmö (Sweden), Milan (Italy), Paris (France), Ploiesti (Romania), Plovdiv (Bulgaria), Prague (Czech Republic), Vienna (Austria) and Vilnius (Lithuania).

The pilot focused on five “workstreams”, where lessons for implementation could most usefully be drawn: *i*) emission inventories, *ii*) air quality modelling activities, *iii*) air quality monitoring networks, *iv*) management practices and *v*) public information.

The results discussed in this manuscript focus exclusively on the workstream related to assessment of air quality modelling activities in the cities. More information about the results and conclusions obtained in the other workstreams can be consulted in the EEA Report No7/2013 [5]. This paper provides a shortened version of the EEA report, highlighting the main results and conclusions obtained in the workstream related with air quality modelling.

METHODOLOGY

One of the aims of the Air Implementation Pilot was to examine air quality modelling practices (where they exist) in the context of the air quality directives [6,7] in the 12 participating cities, to assess to which extent modelling is used, strengths and weaknesses of model applications, and to identify further guidance needed by the cities. The work presented here does not provide precise recommendations on the application of models, but focuses on the experiences of these cities when applying models for air quality assessment and/or management.

According to the current Air Quality Directives [6,7], the main applications of models in relation to air quality legislation are [8]:

- Assessment of existing air quality: to supplement, complement, or replace monitoring stations; and to provide adequate information on the spatial distribution of the ambient air quality.
- Management of air quality and providing assistance in the drafting of the following plans:
  - Long-term air quality plans when limit values or target values are exceeded;
  - Short-term action plans in regard to exceedances of alert thresholds;
  - Joint international air quality plans with other Member States when transboundary air pollution is the cause of exceedances.
- Source apportionment: modelling in combination with monitoring to assess the causes of exceedances and the contribution to pollution from different sources.
- To provide supplementary information for the geographical areas not covered by measurement data. This could serve as a basis for calculating the collective exposure to pollution of the population living in an area.

Additionally, models can also be used to provide complete spatial coverage of air quality, be used prognostically, and to provide improved understanding of the sources, causes and processes that determine air quality.

In order to examine model practices in the 12 cities, a questionnaire was prepared to obtain an overview of the applications for which models are used, gain an insight on how the model has been applied for each of the purposes, and learn about where the modelling competence lies (e.g. authorities, scientific institutions, consultants, etc.) as well as existent cooperative activities with other institutions. The questionnaire was sent to a contact person in each city. The questionnaire aimed to give answers to the following main questions:

a. What types of models have been used?
b. Which particular models?
c. For what purposes are models used?
d. Which input and other data (e.g. emissions, meteorology, observed concentrations, boundary conditions, etc.) have been used and considered?
e. How are models validated?
f. Are the model results considered to be “fit for purpose”?

The questionnaire and the complete analysis can be consulted in the ECT/ACM Technical Paper [11].

RESULTS AND DISCUSSION

All the cities, with the exception of Dublin, have used models for air quality activities. There are several reasons why Dublin has not used air quality models. These reasons include: administrative issues (the difficulty of bringing together the various stakeholders); the current economic situation; and the perception that air quality modelling is an area where there is a lack of the required skill and experience to operate a model.

All of the other 11 cities replied to the questionnaire on modelling activities, with the exception of Ploiesti which instead of submitting the questionnaire, submitted a document informing that models have only been applied for assessing air quality in general and not for other purposes. Therefore, for the sake of comparability, information from Ploiesti has not always been taken into account.

As mentioned before, air quality models can be used for many different purposes. In the questionnaire, the participating cities were asked about eight specific applications:

1. Assessment of air quality in general (including evaluating the impact on air quality of new infrastructure, such as highways, airports, etc).
2. Reporting of air quality compliance assessments (both under the air quality assessment questionnaire and for time extension notifications).
3. Assessment of source contribution.
4. Long-term planning and scenario calculations.
5. Short-term action plans.
6. Air quality forecasting.
7. Assessment of the exposure of populations to air pollution.
8. Supplementing measurements from monitoring stations.

None of the cities have used models for other applications than the eight mentioned above and which applications the cities use models for varies considerably from city to city. Figure 1 shows the summary of the applications for which the ten cities that have submitted the questionnaire have used air quality models.

The information about the models and the purpose it was run has been summarized in the Table 1. As it can be seen in the table, the models applied differ from city to city, and only three models have been applied in more than one city. Different types of models have been employed for the same application:

- For assessment of air quality in general the type of models that have been applied are Gaussian (6), Eulerian (4) and Lagrangian (3), street canyon model (1) and also an statistical model based on interpolation (1).
- For reporting of air quality compliance the type of models applied are Street canyon model (1), Eulerian (2), Lagrangian (1) and Gaussian (1).
- For assessment of source contribution Gaussian (5), Lagrangian (4), Eulerian (4) and also a chemical mass balance model (1) have been applied.
- For long term planning and scenario calculations, Street canyon (2), Gaussian (4), Eulerian (3) and Lagrangian (2) models have been employed.
- For short term action plans Gaussian (4), Eulerian (3) and Lagrangian (2) models have been applied.
- For air quality forecasting, the cities have employed Eulerian dispersion models (2), a statistical model based on neural networks (1), Lagrangian models (2) and Gaussian models (1).

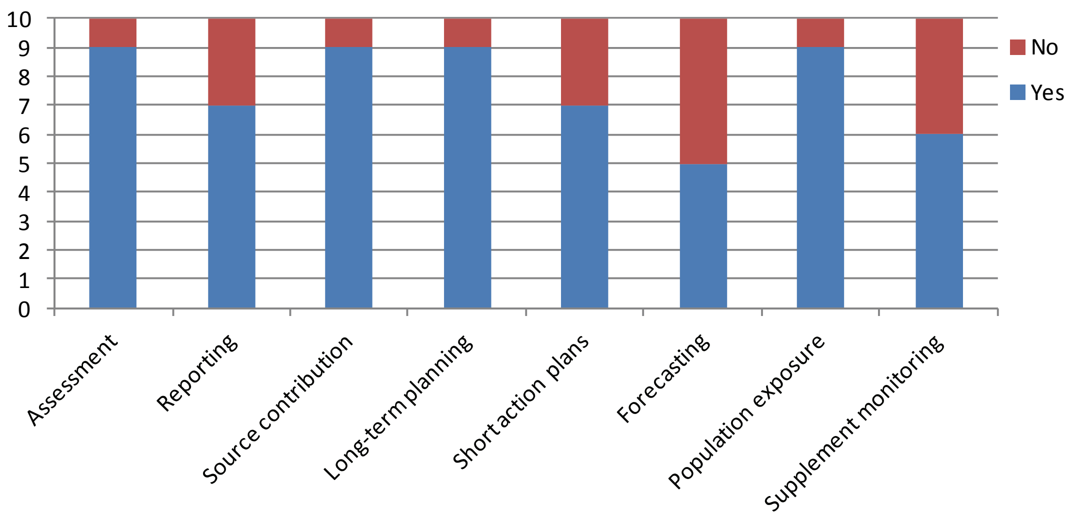

Figure 1. Number of cities, out of the 10 that submitted the questionnaire, that have used models for each particular air quality assessment and management application.

Table 1. Summary of the type of model, applications, and links to documentation of the models used by the cities participating in the Air Implementation Pilot. Applications: 1) assessment of air quality in general; 2) reporting of air quality compliance assessment; 3) assessment of source contributions; 4) long-term planning and scenario calculations; 5) short-term action plans; 6) air quality forecasting; 7) assessment of population exposure; 8) supplement measurements

Name of the model	Type	Applications	City	Documentation
AERMOD	Gaussian	1;3;4;5;7	Malmö	http://pandora.meng.auth.gr/mds/showlong.php?id=128
OSPM	Street canyon	2;5 1;4;7;8	Malmö, Madrid Antwerp	http://pandora.meng.auth.gr/mds/showlong.php?id=74
FARM	Eulerian	1;2;4;5;7;8	Milan	http://pandora.meng.auth.gr/mds/showshort.php?id=130
SPRAY	Lagrangian	3	Milan	http://pandora.meng.auth.gr/mds/showshort.php?id=87
CALPUFF	Gaussian	3 1	Milan Paris	http://www.epa.gov/ttn/scram/dispersion_prefrec.htm #calpuff
CBM	Chemical mass balance	3	Milan	http://www.epa.gov/scram001/receptor_cmb.htm
GRAL modified	Lagrangian	1; 2; 3; 4; 7; 8	Vienna	http://pandora.meng.auth.gr/mds/showlong.php?id=133
CAMx	Eulerian	5; 6;7	Vienna	http://pandora.meng.auth.gr/mds/showshort.php?id=177
SERENA	Statistical neural network	6	Madrid	http://www.mambiente.munimadrid.es/opencms/opencms/calaire/SistIntegral/SistPrediccion.html
CMAQ	Eulerian	2; 3; 4; 5	Madrid	http://www.cmaq-model.org/
WRF-Chem	Eulerian	2; 3; 4; 5	Madrid	http://www.acd.ucar.edu/wrf-chem/
ATEM	Gaussian	1; 2; 3; 4; 5; 7	Prague	http://www.atem.cz/en/atem.html
SYMOS	Gaussian	5	Prague	http://pandora.meng.auth.gr/mds/showshort.php?id=119
REM_CALGRID_RCG	Eulerian	1,3	Berlin	http://pandora.meng.auth.gr/mds/showshort.php?id=173
IMMISluft (IMMIScpb)	Gaussian	1, 3, 4, 7,8	Berlin	http://pandora.meng.auth.gr/mds/showshort.php?id=178
CHIMERE	Eulerian	1;2;3;4;6;7	Paris	http://pandora.meng.auth.gr/mds/showshort.php?id=144
ADMS urban	Gaussian, Lagrangian	1 1,2,3,5,6,7,8	Paris Vilnius	http://pandora.meng.auth.gr/mds/showshort.php?id=18
PMSS	Eulerian		Paris	http://www.harmo.org/Conferences/Proceedings/_Kos/publishedSections/H14-176.pdf
STREET	Street canyon	2; 4; 7	Paris	NA
AUSTAL 2000	Lagrangian	1; 3; 4; 5; 7;8	Plovdiv	http://pandora.meng.auth.gr/mds/showlong.php?id=132
PROKAS_B	Gaussian	1; 3; 4; 5; 7	Plovdiv	http://pandora.meng.auth.gr/mds/showlong.php?id=115
VinMISKAM	Eulerian	1; 3; 4; 5; 7	Plovdiv	http://pandora.meng.auth.gr/mds/showlong.php?id=123
POLTRAN	Eulerian	1; 3; 7; 8	Plovdiv	NA
RIO	Interpolation model	1;4;7;8	Antwerp	http://rma.vito.be/demo/faces/documents/rio/RIO.pdf
AURORA	Eulerian	1;4;7;8	Antwerp	http://pandora.meng.auth.gr/mds/showlong.php?id=167
IFDM	Gaussian	1;4;7;8	Antwerp	http://pandora.meng.auth.gr/mds/showlong.php?id=50

- For assessing the exposure of the population the models used have been Gaussian (5), Eulerian (3), Lagrangian (3), street canyon (1) and interpolation model (1).
- Finally, to supplement measurements the types of models applied are Street canyon (1), Eulerian (3), Lagrangian (3) and Gaussian (3).

There is no single model that can address all the applications. One model that is appropriate for one application may not be suitable for another application. For instance, Eulerian grid models are suitable for environmental assessment where phenomena as advection, deposition and chemical transformation of pollutants are important. However, Lagrangian puff models might be more suitable for evaluating short-duration emissions when spatially varying meteorological fields are crucial.

Gaussian models assumes that the air pollutant dispersion has a normal probability distribution. They are mostly used for predicting the dispersion of continuous plumes. Lagrangian models are characterized for using a moving frame of reference following the pollution plume as it moves in the atmosphere. Eulerian models are similar to Lagrangian as they track the movement of a large number of pollution plume parcels as they move from their initial location, but the main differences is that they use a fixed 3-dimensional grid as reference. Street canyon models are the best suited to represent air dispersion in streets as they consider the effect of buildings in air quality. They are usually nested in Eulerian models, but can also be used as stand-alone models. Chemical mass balance model are used to evaluate the contribution of various pollution sources to the air composition at a location. Neural network and interpolation models are not dispersion models but statistical models. Statistical models usually provide a less data-demanding approach to estimating atmospheric concentrations. A more detailed mathematical description of how each type of model operates can be found in the literature [9,10].

The Model Documentation System (MDS) provides guidance to any model user in the selection of the most appropriate air quality model for his application. Almost all the models mentioned here are documented in the (MDS). Only two models do not have public documentation available. More detailed information about the models and its applications can be found in the ETC/ACM Technical paper [11] and the references there.

In terms of the input data used for the modelling, emissions, meteorology and boundary conditions, the data employed depend on the type of model, the purpose of application, and on the information available. From the information provided by the cities it was found that:

- *Emission inventories.* Cities have developed a specific local emission inventory to run the model, and the spatial and temporal resolution of the emission inventories vary according to the model used and the resolution employed in the air quality (AQ) modelling. For instance, spatial resolution goes from 24 m in the AUSTAL 2000 (Plovdiv) or 50 m in the OSPM model (Malmö) to 4×4 km^2 in the FARM model (Milan); the temporal resolution employed is hourly or annual. The sources included in the emissions also vary depending on the purpose, model and information available. For instance, in relation to the traffic emissions, all the cities answered that traffic congestion is a problem in their cities with the exception of Vilnius, however not all the models are capable of reflecting it. For instance, FARM (Milan) or REM_CALGRID (Berlin) do not take into account traffic congestion, and the cities of Paris and Plovdiv also indicate the difficulties in modelling traffic congestions as traffic emissions are based on traffic counts that cannot completely reflect congestion effects. Other traffic emissions that are usually not included are the non-exhaust emissions. For commercial and domestic sources the precise location within the city is not always known. A further difficulty is the lack of data on the emission height of these sources.
- *Meteorology.* Meteorological data for air quality modelling are obtained from different sources such as measurement towers (as in the case of Malmö, Prague, Berlin, Plovdiv, Antwerp), high resolution meteorological models (as in the case of Madrid, Vienna and Paris), or model results combined with a local monitoring network (as in the case of Milan).
- *Background concentration.* The background concentration of pollutants is considered in all the cities, but using different sources as for instance: 1) estimation from modelling of regional sources together with several measurement stations (Malmö); 2) estimation from monitoring data from background stations and emission inventories of neighbouring provinces when needed (Vienna, Paris, Plovdiv, Vilnius and Antwerp); 3) provided as boundary conditions under nesting models (Madrid), other regional models (Berlin, Vilnius) and models run at national level for forecasting (Vilnius); 4) European simulations (Berlin).

To evaluate the results of the model, the cities compare the model output against local measurements and use indicators as for instance bias, root mean square error, mean error correlation, etc. Most of the cities have also estimated the 'uncertainty' (accuracy) of their air quality model, as required by EU legislation [6,7].

In the questionnaire sent to the cities it was also asked a personal evaluation of the usefulness of the model and of the challenges found in the application of models for air quality assessment and/or management. The answers showed that all the cities have found their models to be helpful for the purpose for which they were implemented. Furthermore and in general, the model results have been considered in air quality management decisions.

Regarding the challenges encountered when running the models, five points were mentioned by almost all the cities:

- *Input data quality and availability*. For instance emission inventories, estimation of background concentrations at national and international level, or the lack of good quality urban meteorological data.
- *Technical difficulties on representing the physical and chemical processes in the city*. For instance, traffic congestion, hot spots, etc.

- Dealing with the uncertainties in the model results, as for instance overestimations and underestimations in the pollutant concentrations.
- The resources required, not only in terms of computational time and computing servers, but also in terms of personnel competence. As commented before, this is the main reason most of the cities don't run the model themselves and collaborate with universities or research institutes.
- *Interpretation of the results*. Linked with the two points mentioned before, the results are complex and their interpretation requires a high degree of competence within air quality modelling.

In view of the results and the comments expressed by the cities, improvement in modelling activities could come from the following areas [5]:

- Training/guidance on how to use a model, how to apply it, and how to validate it. Training is also needed on how to know which model to use.
- Improvement of input data, for instance to take into account the urban topography.
- Production of emission inventories with the better quality/accuracy of the emission data (emission rates and emission conditions (*e.g.*, height) and adequate spatial and temporal resolution for the model application.
- Creation of a service that provides cities with background concentrations as an input for their models.
- Creation of a general framework for modelling, criteria harmonisation, and exchange of experiences. The involvement of cities in FAIRMODE activities (http://fairmode.ew.eea.europa.eu) can be a way of promoting this exchange of experiences.

CONCLUSION

All the cities participating in the Air Implementation Pilot applied air quality models, except for Dublin. Models have been used for different purposes, *e.g.*, reporting of air quality compliance, source apportionment, population exposure estimation and/or long term planning. Not all the cities have applied models for all the purposes. Moreover, most of the cities have established some collaboration with universities and research institutes, and only two out of ten have enough technical and professional resources to run the models themselves.

All the cities expected to learn about how other cities have applied air quality models and share experiences. The project identified needs for further support in the use of air quality models, including training, establishing discussion forums, or providing better input data.

Despite the challenges in the application of models, all the cities have found models helpful for the applications they were used for, and the outputs have been employed for air quality management decisions.

The Air Implementation Pilot has shown that enabling authorities and experts to exchange experiences and knowledge will promote a better understanding of issues related to the implementation of air quality legislation, including within the use of models for air quality assessment and management.

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NAUČNI RAD

ULOGA MODELOVANJA KVALITETA VAZDUHA U UPRAVLJANJU ČVRSTIM ČESTICAMA U GRADOVIMA. REZULTATI PROJEKTA "*AIR IMPLEMENTATION PILOT*"

Evropska komisija i Evropska agencija za životnu sredinu - EEA su se dogovorili da pojačaju napore da bi poboljšali znanja o primeni propisa o kvalitetu vazduha kroz zajednički pilot projekat. Ovaj projekat je trajao od marta 2012. do juna 2013. godine, a imao je za cilj bolje shvatanje izazova sa kojima se suočavaju gradovi u sprovođenju politike kvaliteta vazduha. Dvanaest evropskih gradova je izabrano i pozvano da učstvuje u ovom projektu. Jedan od glavnih ciljeva pilot projekta zbog koga su gradovi primenili modelee je bio da se oceni korišćenja modela za procenu i upravljanje kvalitetom vazduha, razmena iskustava i identifikacija potreba za daljim uputstvima. U ovom radu su prikazani rezultati analize primenom praksi modelovanja. Više od 20 različitih modela su korišćeni za procenu i upravljanje kvalitetom vazduha u ovim gradovima. Glavna svrha zbog koje su gradovi primenili modele su ocena kvaliteta vazduha, kvantifikacija doprinosa izvora i dugoročno planiranje. U gradovima je utvrđeno da su modeli bili od pomoći jer su dobili rezultate korisne za procenu i upravljanje kvalitetom vazduha u urbanim sredinama, uključujući i procenu strategija za smanjenje nivoa respirabilnih čestica u ambijetnoj sredini. Međutim, u gradovima se nailazilo i na teškoće tokom primene modela kao što su, na primer, kvalitet i dostupnost ulaznih podataka ili validacija i procena nesigurnosti rezultata modelovanja.

Ključne reči: modeli kvaliteta vazduha, upravljanje kvalitetom urbanog vazduha, respirabilne čestice, zakonodavstvo EU.