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EMISSION NEEDS AT LOCAL SCALE FOR AIR QUALITY MODELLING

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Abstract: One of the objectives of the Forum for Air Quality Modelling in Europe (FAIRMODE) is the definition of a quality assurance system for air quality modelling activities involved in the application of the European Air Quality Directive (AQD). The fulfilment of certain model quality objectives (MQO) and therefore, the acceptability of modelling results in the scope of the AQD, are closely related to the minimization of model uncertainties. Emission input to air quality models (AQMs) is one of the main sources of uncertainty. Beside emission estimation itself, emission inventory preparation is a critical stage in air quality modelling. Consequently, emission-related inputs play a vital role in all the main topics abovementioned. As a response to the need of investigating the methodologies and best practices to deal with emission inputs, the WG2 of FAIRMODE includes a specific sub-group (SG3) on emission-related issues.
This paper presents the SG3 background document that provides a framework for emission compilation at urban level, taking into account the need for consistency with national or regional inventories, combination of top-down and bottom-up approaches, use of GIS and specific requirements of the chemical-transport and dispersion models needed to assess pollution levels in urban areas. The aim of this document is to build on the general findings of previous references and to reflect on the ultimate reasons for the lack of consistency of emission inventories through the scales/models so preliminary guidance on the key issues to be considered when developing urban scale inventories and scenarios can be given. This draft is also meant to foster the discussion and exchange in the FAIRMODE forum.
The paper gives some references to meet the basic requirement of emission information from the perspective of the acceptability of AQ modelling results (i.e representativeness). Representativeness implies that emission inventories and projections are acceptable or reliable enough regarding i) coverage of emission sources and pollutants, ii) reliability, and iii) spatial and temporal resolution. Each criterion is analysed proposing requirements, criteria, quality check procedures, recommendations, and general remarks to help to produce robust and meaningful emission inventories and projections.

***Key words:** Emissions, Air Quality Modelling, Representativeness, Uncertainty.*

INTRODUCTION

The Forum for Air Quality Modelling in Europe (FAIRMODE) is an EU-wide Air Quality Modelling Network in support to the implementation of the new EU Air Quality Directive, AQD (Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe). The definition of a quality assurance system of air quality modelling activities involved in the application of the AQD is the main concern of the FAIRMODE WG2. Such modelling activities are related to four main topics according to the AQD:

- Assessment of ambient air quality (replacing or complementing monitoring data)
- Planning and mitigation strategies
- Assessment of the contribution of natural sources, road dust and sea salt
- Short-term forecast for threshold exceedances

The fulfilment of certain model quality objectives (MQO) and therefore, the acceptability of modelling results in the scope of the AQD, is closely related to the quantification of model uncertainties. Emission input to air quality models (AQMs) is one of the main sources of uncertainty. This issue is also relevant for the analysis of the alternatives to improve air quality in a given region in future years as a result of the implementation of pollutant emissions abatement strategies and from the integrated assessment modelling point of view. Beside emission estimation itself, emission inventory (E.I.) preparation is a critical stage in air quality modelling. Consequently, emission-related inputs play a vital role in all the main topics abovementioned. As a response to the need of investigating the methodologies and best practices to deal with emission inputs, the WG2 of FAIRMODE includes a specific sub-group on emission-related issues. Such issues involve a variety of pollutants, methodological aspects and scales. It was agreed, however, that FAIRMODE activities should be focused on the urban scale, were the lack of consistent emissions inventories and projections needed for the application of the AQD is more evident. The main objective for a first step was to present a framework for emission compilation at urban level, taking into account the need for consistency with national or regional inventories, combination of top-down and bottom-up approaches and use of GIS and other tools to support AQ assessment, implementation of AQ action plans, development of plans to postpone the deadline for compliance of AQ limit values or short-term forecast.

All uses of modelling techniques for these applications involve air quality (AQ) assessments at different spatial scales, either to represent the effect of policies and measures at different scales or to provide boundary conditions for local or microscale applications. Sound and generally accepted methodologies for emission compilation are available at continental and national scales (e.g. EMEP/EEA guidebook, IPCC guidelines, etc.). AQ modelling at urban scale, however, usually requires the compilation of ad-hoc bottom-up inventories. Such inventories have to meet the particular requirements of the modelling tool being used and have to be meaningful from the point of view of abatement options and environmental policies. Although a general framework is not available, there are a number of initiatives and references that are useful to get a better insight of the main sources of uncertainty and inconsistencies. The aim of this document is to build on the general findings of previous references and to reflect on the ultimate reasons for the lack of consistency of emission inventories through the scales so preliminary guidance on the key issues to be considered when developing urban scale inventories and scenarios can be given.

More information, related documents and summaries from previous meetings are placed at the FAIRMODE Web Page (http://fairmode.ew.eea.europa.eu/).

AVAILABLE METHODOLOGIES TO DEVELOP URBAN SCALE INVENTORIES

There is no much guidance to develop urban scale inventories for AQ modelling purposes apart from the information that could be extracted from official inventories of some European cities such as Berlin, London (Mattai, J. and D. Hutchinson, 2008) or Paris. However, references about Green House Gases inventory compilation are more abundant. Nevertheless, they are often aimed at developing a 'carbon footprint', so that approaches are based on final energy consumption of the city including both fuels and electricity or heat. This means that these inventories do not include only emissions derived from activities within the city but also emissions generated outside the domain in facilities to produce final energy consumed in the urban area (e.g. power plants located outside the city). One of the main references is the GHG protocol (http://www.ghgprotocol.org), developed by the World Resources Institute / World Business Council for Sustainable Development (WRI/ WBSCD5), that is very widely used by many cities and organisations. It includes comprehensive emission inventory guidance and different scopes/techniques established to cover the different boundary conditions desired (i.e. just direct emissions or including indirect plus embedded emissions). The guidebook to develop Sustainable Energy Action Plans (SEAP manual) (European Union, 2010) produced by the Covenant of Mayors (http://www.eumayors.eu) provides specific guidance to estimate GHG emissions at urban level. The second part of the manual consists of a guidance to produce baseline emission inventories and includes emission factors (E.F.) for the main emission sources (fuels, electricity and heat/cold), advice for activity data collection, and help to use existing tools.

Although AQ modelling inventories have different requirements concerning the geographical scope, much of the guidance on these GHG references (emission factors, how to acquire data, good practice, etc.) remains valid. The accuracy of the emission estimation itself (computation methods, E.F., databases) is a basic requisite for any inventory. However, inventories aimed at modelling AQ present specific requirements that lead to substantial differences apart from geographical scope and accounting criteria. The main particular inventory features critical for AQ modelling are:

- Spatial allocation (surrogate definition, landuse and population density covers)
- Temporal allocation (inventory categories and temporal patterns)
- Chemical speciation (inventory categories, chemical mechanisms, cross-references)

There are many references in the literature on alternative options to cover these features. Concerning emission data accuracy, Cho et al., 2009 analysed, as and example for PM simulations, the effect of including emission corrections for coal fired power plants based on continuous monitoring system data, at-source emission measurement data, and observations at the stacks. With regard to spatial resolution and emission allocation, Mensink et al., 2008 presented examples of scale interactions in local, urban, and regional air quality modelling whilst Cheng et al., 2008 illustrated the influence of land cover and land use resolution on AQ simulation for a metropolitan area in the States. As for temporal disaggregation, Wang et al., 2010 presented the sensibility of AQ simulations using WRF-Chem model to the variation of temporal emission distributions while Kühlwein et al., 2002 showed the influence of using precise daily and weekly traffic distribution based on traffic counts compared to default average curves.

A first literature review and analysis of the recent and ongoing activities shows that substantial knowledge and guidance about emission inventory compilation is available. Nevertheless, there are no unified criteria or specific procedures for A.Q. emission inventory compilation at urban scale. In the next section, a series of general criteria for inventory harmonization and compilation are presented as a summary and preliminary approach to fill this gap as far as the AQD is concerned.

KEY ISSUES TO DEVELOP URBAN EMISSION INVENTORIES

The basic requirement of emission information from the perspective of the acceptability of AQ modelling results is representativeness. Representativeness implies that the emission inventory is acceptable or reliable enough regarding the following criteria:

- Adequate cover of emission sources and pollutants
- Emission estimate reliability / uncertainty
- Appropriate spatial and temporal resolution

Although the representativeness of an emission inventory may be assessed by these general principles, actual requirements for a given application depend on the purpose of the analysis, i.e., the modelling system, the modelling domain and setup and the purpose of the simulation.

Usually, a combination of models is used for urban-scale AQ assessments. For instance, the analysis required to apply for a postponement of the deadline for compliance of the NO_2 limit values, would rely on an Eulerian nested photochemical model and on some kind of microscale or street canyon stationary model. The concept, formulation and information needs differ considerably. Even for urban-to-regional scale AQ or action plan assessments, the application of a single mesoscale model may involve two or more emission inventories in order to provide accurate boundary conditions that may capture influences from outside of the innermost modelling domain. A general principle to be observed when developing an emission inventory or combining different scale inventories already in existence, is to keep the consistency. A fine-resolution inventory may be restricted to specific areas and/or pay special attention to some particular sector where the main emission reduction measures will be placed, i.e. traffic, and therefore, the comparison with, e.g. national inventories, may not be possible in strict sense. Nevertheless, some general requirements to develop consistent and accurate emission inventories at urban scale are as follows:

1.- Emission inventory compilation or emission estimates must be based on a general methodology such as the EMEP/EEA guidebook or emission factors database or computed in accordance to a transparent and sensible method

2.- Even when different scale inventories are based on the same methodology, substantial discrepancies may arise. A minimum set of checks must be performed to find out possible biases:

- sources included in the inventory
- comparison of emission factors used for the main sectors and pollutants
- references and comparison of statistics used, differences in the statistical information used as activity rates (sources, criteria, updates)
- aggregation of the bottom-up inventory to a common geographic reference and comparison with the top-down approach.

All this issues must be properly referred to or documented so that the inventory is transparent and it is possible to understand the reasons for potential differences, limitations and implications/recommendations for the interpretation of the modelling results based on this input. In addition, transparency plays a vital role on the exchange of information that may be relevant for other inventories/areas.

3.- As for an adequate cover of pollutants and sources, some criteria to follow can be:

- Any urban inventory must include an estimate of the complete set of sectors with relevant emissions depending on the simulation purpose. It is important to include any relevant sector, understanding that some of them may be very specific for a particular region (e.g. fireplaces, traditional ovens or stoves, etc.), or may be especially significant policy-wise. Even for some sectors that are not important a priori (e.g. agriculture, off-road mobile sources), a rough estimate or derivation from larger-scale inventories should be given to provide a general view of emissions in the modelling domain.
- The inventory must include accurate and detailed emissions regarding the key sectors according to the preliminary analysis abovementioned. All relevant sources must be included. If is not feasible to include all sources, a reference of the cover and limitation of the inventory should be given and justified.
- The emission information must be in agreement with the specific requirements of the modelling system, paying special attention to critic parameters, i.e. NO_X speciation in applications aimed at the assessment of NO_2 ambient concentration. If expert judgments or non specific references are used, their convenience should de discussed and carefully analyzed. Input information can be as limiting as model formulation. If the involved uncertainty results unacceptable, it may be opportune to re-evaluate the convenience of the modelling system. A simpler model, using specific and controlled information, may result better fitted for purpose in that case.

4.- Emission reliability may be hard to check. Some possible options to limit the uncertainty are as follows:

- Emission estimates must be based on validated E.F. databases, accepted and well-documented software, etc.
- Emission computation for relevant sectors in the urban scope, such as traffic, is usually based on complex methods that require a large number of inputs besides emission factors. Activity data and ancillary information (e.g. traffic intensity, fleet composition, average speed), should be as much as possible, based on observations and official records. In the absence of such information, updated statistics should be used. It is essential that the inventory includes a detailed description and discussion of the origin of these datasets to understand their suitability and possible limitations. Similarly, emission measurements, or facility-specific statistics (bottom-up approach) for industrial, commercial and residential sectors are preferred.
- If more than one inventory happen to exist for a particular urban area, it is interesting to compare them to detect methodological divergences and be aware of the emission estimation spread. If possible, an emission inventory evaluation via AQ modelling (degree of agreement of air quality observations and the results of an AQM feed with that emission information) may provide very helpful information to understand the accuracy of an emission estimate.
- If differences between inventories are based on basic statistics used to build the inventory (e.g. local and national energy balances), the analysis should be focused on the methodological approach (fuel categories, boundaries, criteria for computation of inputs, outputs, etc.) and information sources considered.

5.- An accurate spatial and temporal distribution may be as important as the emission estimation itself in order to provide a representative description of the pollutants emitted to the atmosphere in a given region, and therefore the corresponding ambient concentration levels. To some extent, this issue is closely related to the issues listed above (emission measurements, observed activity data). However, special attention should be paid to the particular needs of the modelling system being used:

- The bottom-up approach (geo-referenced emissions) is preferred when there is information enough to support a very detailed emission estimation (complete and exhaustive description of individual emitters) and to produce a basis to propose effective emission reduction measures. However, a top-down approach in combination with an updated high-resolution landuse/population cover may provide a valid picture of general emission distribution pattern. If basic reference statistics are properly harmonised (which is not an easy task), both approaches should lead to quite similar results, being the differences due to the use of more specific information available only at finer scales. GIS information used to support the surrogate data in top-down approaches and model grid should have a proportional spatial resolution. Downscaling of regional gridded emission inventories should be driven similarly by meaningful, updated and accurate GIS information. The relationship between surrogate data (i.e. population density) and emissions to be spatially allocated (i.e. residential heating) must be as specific as possible.
- Vertical allocation of emissions for 3D models should be suitable for the vertical model structure (proportionate to the horizontal resolution). Release conditions for buoyant emissions should be dealt with properly (temperature, vertical velocity, etc.) for point sources.

• Hourly measured emissions are to be used if possible. If measurements are unavailable, source-specific temporal patterns must be used (e.g. specific industrial activities, vehicle type hourly fluxes, etc.). It may be necessary to use several temporal patterns for a single source in different areas of the modelling domain.

KEY ISSUES TO DEVELOP URBAN EMISSION PROJECTIONS

AQ modelling is an important tool to assess current conditions but it is essential to estimate future pollution levels, either for short-term forecasting or scenario analysis. Emission abatement usually entails significant costs and some measures may find public opposition. The generation of emission inputs for the assessment and planning of mitigation strategies is a key requirement for the design of an efficient policy. Technically, any future emission scenario has to meet the same requirements as presented in the previous section for the emission inventory. Moreover, representativeness in this case also depends on the accuracy of the simulation of the impact (in terms of emissions) that a particular measure would have if implemented.

Since it is unfeasible to establish particular requirements or criteria for emission scenario development, some general remarks that may help to produce robust and meaningful emission projections are as follows:

1.- The level of detail of emission projections for a particular source/sector should be consistent with the detail corresponding to the base year emission inventory
2.- Future-year emission estimates should be ideally based on the same computation algorithms
3.- Variation in the emission factors, and or activity levels should be well documented and supported by consistent emission databases, activity level projections and plan targets. Information regarding the methods considered to assess the effectiveness or expected outputs (emission abatements) from particular measures may contribute significantly to the transparency of the analysis. This is particularly important for non-technical measures.
4.- Alternative urban emission scenarios may be consider, usually a Baseline (with measures) and a Policy scenario (with additional measures). It is essential that these of any other scenarios include possible implications derived from policies and measures (P&M) at different administrative level (i.e., European, national, regional, and local). Special attention should be paid to avoid double-counting of P&M effects.
5.- Regardless of the emission computation error, an important uncertainty may be brought about by measures and policies considered. An estimate, even qualitative, of the likelihood that a particular measure has to be actually implemented may be difficult to make. Even though, measures which implementation is unfeasible or unlikely can distort the interpretation of Baseline scenario and provide misleading results. References to the instruments envisaged to implement particular measures should be given if available.
6.- As mentioned before, the methodology and ancillary information needed to develop emission scenarios has to be consistent with the methods used for the reference emission inventory. This does not mean that temporal or spatial patterns have to remain identical. Some measures may have an impact on either temporal or spatial emission patterns. If this is the case, changes should be highlighted and discussed (e.g., alternative spatial allocation of projections related to urban planning, new developments, etc.)
7.- A detailed description and documentation of the underlying hypotheses considered, both for the measurements included and the emission estimation methodology should be included

CONCLUSIONS

Information on urban emissions and projections is necessary for AQ assessment, development of AQ action plans, and short-term forecast. Moreover, they are essential to determine the origin of exceedances to limit values and to identify means to reduce them in the future. In this sense, some recommendations were prepared to help emission inventory and projections compilers to improve their current work and they were presented in the previous sections.

Additionally, in the last FAIRMODE meeting hold in June 2011, subgroup 3 (urban emission and projections) concluded that the current methodologies widely used (top down approaches for downscaling emissions from regional to urban scale) are not sustainable because they do not enable the necessary link between measures, plans and emission reductions at urban scale. Therefore, at urban scale, bottom-up approaches are necessary. To do so, SG3 aims to be an open forum for exchange of expertise and information on the bottom-up compilation of urban emissions and the evaluation of urban control measures. As a consequence, during the next year, the group will map current practices for compilation of urban emissions, extend and improve both recommendations on best practices for urban inventories and procedures to develop emission projections consistently with emission inventories at urban level and it will also identify essential data and information that needs to be made available to facilitate the implementation of those best practices and procedures. Accordingly, an emission inventory questionnaire were developed which will be completed by EU inventory compilers for each of the main emission sectors individually (transport; residential, commercial and institutional; industry, energy and waste management; and agriculture/nature). It includes specific multi-choice questions depending on methodological approach (top-down, bottom-up or hybrid).

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