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Overview of current regional and local scale air quality modelling practices: Assessment and planning tools in the EU

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ABSTRACT

The 2008 European Air Quality Directive (AQD) (2008/50/EC) encourages the use of models in combination with monitoring in a range of applications. It also requires Member States to design appropriate air quality plans for zones where the air quality does not comply with the AQD limit values. In order to cope with these various elements, a wide range of different modeling methods have been developed and applied by EU Member States in the last decade to assess the effects of local and regional emission abatement policy options on air quality and human health. However, an overall review of the methodologies that are used in different countries to compile local and regional air quality plans has not been performed so far. Such a review has been the objective of the APPRAISAL EU FP7 project with the main goal to identify methodologies and their limitations and to propose possible key areas to be addressed by research and innovation on the basis of this review. To fulfill these objectives, a structured online database of methodologies has been developed in collaboration with experts involved in the design of air quality plans (AQP). The current work relies on the APPRAISAL database which currently totals 59 contributions from 13 Member States. In this paper we summarize the outcome of the APPRAISAL project with respect to the review of current Integrated Assessment Modeling practices.

1. Introduction

The 2008 European Air Quality Directive (AQD) (2008/50/EC) encourages the use of models in combination with monitoring in a range of applications. It also requires Member States (MS) to design appropriate air quality plans (AQP) for zones where the air quality does not comply with the AQD limit values, i.e. to plan possible emission reduction measures to improve air quality. These emissions reductions should be implemented in a cost-effective way through the territory. Obligations resulting from other EU directives (e.g. the National Emission Ceiling Directive) and targeting more specific sectors of activity (e.g. transport, industry, energy, agriculture, etc.) must also be considered when designing

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and assessing local and regional air quality plans (Syri et al., 2002; Coll et al., 2009). In order to cope with these various elements, a wide range of different modeling methods have been developed and applied by EU Member States in the last decade to assess the effects of local and regional emission abatement policy options on air quality and human health. These modeling methods range from simple scenario approaches, i.e. running the model with/without a specific emission source to quantify its impact on air quality levels (e.g. Cuvelier et al., 2007; Thunis et al., 2007; De Ridder et al., 2008) to more comprehensive ones like full cost-benefit analyses (Carnevale et al., 2012; Mediavilla-Sahagun and ApSimon, 2013), in which abatement measures as well as their benefit are monetarized.

However, an overall review of the methodologies that are used in different countries to compile local and regional air quality plans has not been performed so far. Such a review has been the objective of the APPRAISAL EU FP7 project (http://www.appraisal-fp7.eu) with the main goal to identify methodologies and their limitations and to propose possible key areas to be addressed by research and innovation on the basis of this review. To this end, a structured online database has been developed in collaboration with experts involved in the design of AQP. The following topics were considered: (1) synergies among national, regional and local approaches, including emission abatement policies; (2) air quality assessment, including modelling and measurements; (3) health impact assessment approaches; (4) source apportionment; and (5) uncertainty and robustness, including Quality Assurance/Quality Control (QA/QC).

The current work relies on the APPRAISAL database which currently totals 59 contributions from 13 MS. Two groups were distinguished to refine the analysis: the stakeholders involved in the design of "air quality plans" (AQP) and groups involved in "research projects" (RP). While AQP, which represent 60% of the database information coming from 10 MS, is representative of current practices in the decision process, RP (30% of the database contributions, coming form 7 MS) are usually assumed to be based on the most updated methods. Countries represent the study area in 20% of cases, regions in 25% and agglomeration or urban level in 30% of the cases. The remaining percentage refers to other types of focus which could not be classified in these categories. Note that the database (http://servizi.appraisal-fp7.eu/appraisal/faces/pages/public/query.xhtml) is still open to contributions. An example of the current status (September 2015) is presented in Fig. 1 where the contributions are represented per country. Local planning authorities (e.g. municipality) represent 25% of the respondents whereas universities, research institutions, environmental agencies represent each, about 20%.

The final purpose of this review is to contribute to improved knowledge on integrated assessment for air quality plans on the regional and local scales and to improve the use of scientific knowledge by policy makers and regulatory bodies across member states.

In the present paper we focus only on the second topic of the database, i.e. on the air quality assessment. Companion papers (Rasoloharimahefa et al., 2016; Carnevale et al., 2016; Viaene et al., 2016) are devoted to the other aspects of the database. Section 2 details the approach followed to review the methodologies used to assess air quality, along 5 subtopics detailed here per section: Section 3 gives an overview of existing integrated assessment tools; Section 4 focuses on their air quality modelling component; A particular attention is given to resolution and downscaling in Section 5, whereas emissions and other model inputs are discussed in Section 6; finally, we assess in Section 7 the way in which measurements and modelling are associated within these methodologies both in terms of data-assimilation and evaluation of the model performance.

2. Methodology

In order to characterize the usage of AQ assessment and planning tools, the APPRAISAL questionnaire included questions around a topic called "Air quality assessment and planning, including modelling and measurement".

Questions addressed the following points: purpose of the modelling (air quality assessment, mitigation and planning, source apportionment), the strategy followed (scenario analysis, cost-benefit, cost-effectiveness, multi-objective approach), the type of source-receptors approach used (methodology, spatial and temporal resolutions, indicators), the modelling approaches (models, processes, spatial and temporal resolutions, nesting), the input data including emissions (inventory approach, split into activity sectors, resolution . . .), the meteorological input (models, processes, time and spatial resolution), the initial and boundary conditions and some information on the use (or not) of measurements (measurements method, type and location of the monitoring stations, temporal resolution, transformation of the data if

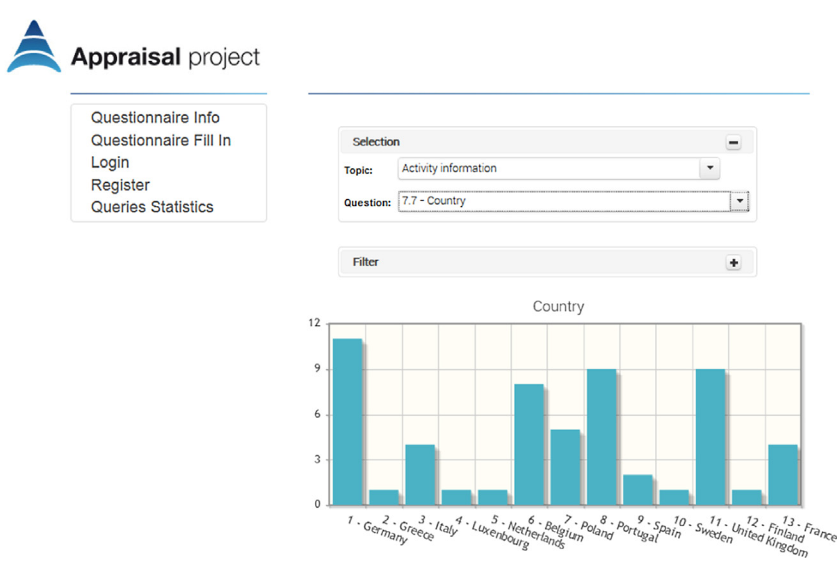

Fig. 1. Screenshot of the Appraisal query selection with a specific application to the current database contributions in terms of countries.

any). The final air quality plan indicators (e.g. mean concentration, percentiles . . .) were also addressed. For most questions, a series of options was proposed. The feedback from several air quality planners was asked to improve the questionnaire and make sure all questions and proposed answers could be fully understood. The questionnaire was then made available to all. In the following sections, 5 subtopics are analyzed.

For each of them the methodological state of the art is presented first while the database is used in a second step to compare current practices with the state of the art. It is important to note that while the state of the art is organized as a review of best practices, independent of the APPRAISAL database, current practices rely on the APPRAISAL database of methodologies that provides an overview based on the available responses to the questionnaire. Cautious is therefore required when interpreting and discussing current practices as some bias might be introduced due to the method in which the data have been collected. However the database already represents a good starting point, with 59 responses.

3. Integrated assessment

3.1. State of the art

In the last two decades atmospheric modelling experienced important improvements. Nowadays, a large variety of modelling systems and options exist, from simpler to more complex ones, covering global/regional to urban and street level scales.

In the scope of air pollution mitigation strategies, integrated assessment modelling (IAM) methodologies have received increasing attention both in the scientific literature as well as in the European air quality directives (e.g. Vinuesa et al., 2003; Carslon et al., 2004; Moussiopoulos et al., 2005; Oxley and ApSimon, 2007; Amann et al., 2011; Giannouli et al., 2011; Carnevale et al., 2012). IAM provide a framework for bringing together disparate information related to a particular problem; this includes data on source emissions, atmospheric dispersion and deposition, the capacity of the receptors to sustain certain levels of concentration/deposition and the cost of abating emissions (Lowles et al., 1998). Hence IAM include tools that allow a user to design air quality plans taking into consideration the impacts of different policy options. General information on IAM can be found in Volta et al. (2016).

The purpose of this section is to summarize the current state-of-the-art in IAM.

IAM can be broadly grouped into two main categories: (a) the scenario analysis (Vinuesa et al., 2003; Vautard et al., 2007) which consists in defining a set of abatement measures and assessing its impact on air quality through modeling and; (b) the optimization analysis which uses algorithms to automatically minimize costs and/or maximize benefits on top of the emission-concentration relationships with a view of delivering a set of cost-efficient abatement measures to the policy maker (Amann et al., 2012; Mediavilla-Sahagun and ApSimon, 2003, Vlachokostas et al., 2011; Guariso et al., 2004). While measures (issued from local expert's knowledge and judgment) are the input in the scenario analysis, they constitute the final results of the optimization in the second.

The optimization approach can include:

- cost-benefit analysis (Moussiopoulos et al., 2005; Vlachokostas et al., 2009) that balances all costs and benefits associated to an emission scenario and identifies an optimal solution;
- cost-effective analysis (Mediavilla-Sahagun and ApSimon, 2013; Carslon et al., 2004; Amann et al., 2011) that has been introduced in order to take into account the high uncertainty affecting the quantification of costs and benefits of non-material issues (e.g. cost of human life);
- multi-criteria approach (e.g. ELECTRE approaches, as in Vlachokostas et al. (2011)), used to explicitly consider multiple criteria in decision-making environments;
- multi-objective analysis (Guariso et al., 2004; Carnevale et al., 2007; Pisoni et al., 2009) that performs a selection of the efficient solutions, considering in a vector objective function all the targets regarded in the problem, and stressing conflicts among them.

IAM Models can be classified in terms of their spatial scale of application:

- At the EU level, the state-of-the-art regarding decision-making tools is GAINS (Greenhouse Gas and Air Pollution Interactions and Synergies) (Amann et al., 2012). The GAINS model is an IAM considering the co-benefits of simultaneously reducing air pollution and greenhouse gas emissions. It has been widely used in the frame of international negotiations to identify cost-optimal allocations of emission reductions across Europe at country level.
- Similar methodologies are also applied at national level: RAINS/GAINS-Italy (D'Elia et al., 2009) and RAINS/GAINS-Netherlands (Jaarsveld, 2004) are two examples in which the RAINS/GAINS methodology has been adapted and replicated at the national level. The FRES model (Karvosenoja, 2008) developed at the Finnish Environment Institute (SYKE) also assesses the effects on the environment of air pollutants emissions, their processes and dispersion in the atmosphere as well as related costs. The PAREST project (Builtjes et al., 2010) and the ROSE model (Juda-Rezler, 2004) are two other examples of national IAM methodologies.
- At the urban/local scale few integrated assessment models have been developed and applied so far. The RIAT/RIAT+ model (Carnevale et al., 2012) computes the most efficient mix of local and regional policies required on top of the Current Legislation (CLE) to reduce pollution exposure and to reach compliance with air quality standards/limit values (e.g. EU directives). The Luxembourg Energy Air Quality model (LEAQ) (Zachary et al., 2011) IAM tool focuses on projected energy policy and related air quality. The tool, initially designed for the Grand Duchy of Luxembourg, is flexible and could be adapted to city scale, provided sufficient information concerning energy use and relevant air quality is available. The UKIAM model (Oxley et al., 2003) explores how to attain UK emission ceilings, while protecting urban air quality, human health and natural ecosystems. Nested within the European scale ASAM model (Oxley and ApSimon, 2007), UKIAM operates at high resolution, linked to the BRUTAL transport model for the UK road network to provide roadside concentrations with respect to air quality limit values, and to explore non-technical measures affecting traffic.

3.2. Current practices

The APPRAISAL database gives us the possibility to compare current practices with the state of art. From this analysis, it appears that IAM is mainly used for defining mitigation measures and planning (Fig. 2). In this respect the main difference between AQP and RP lies in the proportion of IAM used for source apportionment. This application of IAM mainly occurs in "air quality plans" (35% of the AQP) but significantly less in "research projects (roughly 10% of the RP). This might be related to the fact that a quantitative allocation of sources is required in the current legislation while a RP is not necessarily aiming at identifying and/or quantifying the causes of exceedances.

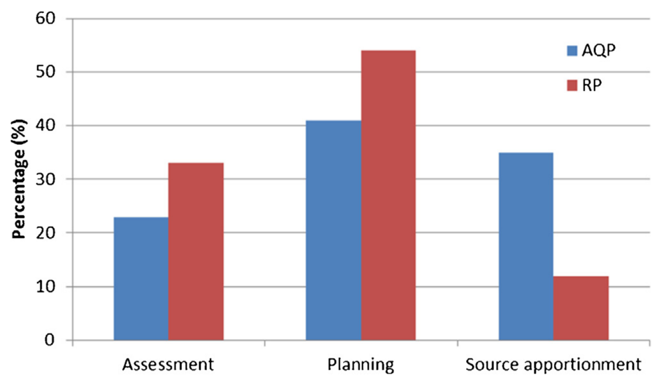

Fig. 2. Main use of IAM tools as reported in the APPRAISAL database (AQP in blue; RP in red). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

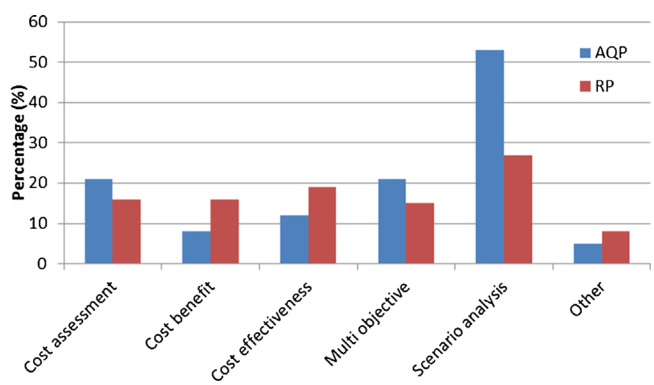

Fig. 3. IAM level of complexity and type of approaches for AQP (blue) and RP (red). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

'Scenario analysis' is most frequently used (Fig. 3), both in AQP (more than 60% of the cases) and RP (roughly 30% of the cases). IAM approaches based on cost-benefit, cost-effectiveness or on multi-objective (i.e. optimization) approaches are used more often in research projects (about 20% vs. 40%) but their use remains limited. One explanation for this low proportion in the AQP might be the fact that these methodologies were not available at regional/urban scales, and to the fact that optimization approaches generally require extensive work to derive relationships to link emissions to air quality (source-receptor relationships) and to collect data related to emission reduction costs and externalities. Indeed these approaches cannot embed full 3D deterministic multi-phase modelling systems because of their prohibitive computational requirements. Although these more complex cost-benefit, cost-effectiveness and multi-objective approaches are not widely applied in the scope of AQP, 20% of the contributors reported using them.

It is also interesting to assess which priorities were identified when designing air quality plans and running research activities. To this end participants were asked (when filling in the questionnaire) to indicate which were the key foci/objectives of their AQP and RP. The following priorities were proposed to choose from (Compliance achievement, population exposure, ecosystem exposure, internal costs (e.g. costs of application of specific measures), green-house gases (GHG) and external costs (e.g. hospitalization) (Fig. 4).

These reported priorities are focused on compliance achievement and population exposure followed by emission reduction costs (internal costs) and costs mainly related to the negative impact of air pollution on human health (external costs).

4. Air quality modeling: a key component for IAM

4.1. State of the art

Air quality models constitute one of the main components of IAM systems used to assess the effectiveness of control strategies adopted by regulatory agencies. The Model Documentation System (MDS) (EEA, 2011; last updated in 2009) provides a comprehensive overview of the air quality models currently used in Europe (http://acm.eionet.europa.eu/databases/MDS/index_html). Additional information about a wide range of meso-scale air quality and meteorological models was also produced by the COST 728 and 732 Actions (2011) (http://www.mi.zmaw.de/index.php?id=6295&no_cache=1). In general one can distinguish the following model main sub-categories: (a) Gaussian; (b) Statistical; (c) Lagrangian, and (d) Eulerian including Computational Fluid Dynamic (CFD) (Lateb et al., 2016) and mesoscale chemical-transport models (Kukkonen et al., 2012).

In the following section, we assess how respondents to the APPRAISAL survey perform their modelling tasks, in particular the type of modelling approach they use and the importance they give to this task in their AQP assessment or RP.

4.2. Current practices

The APPRAISAL database indicates that National, Regional and Local Authorities use a large variety of air quality models to design

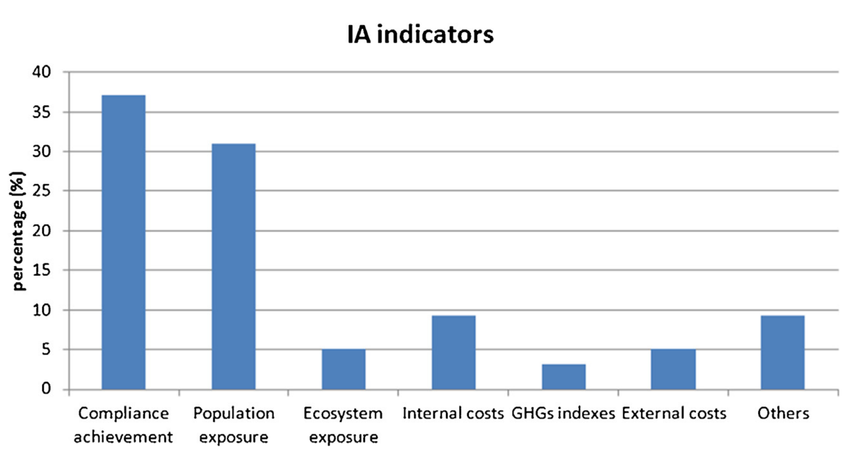

Fig. 4. Main indicators on which IAM tools focus.

their Air Quality Plans and assess their impacts on air quality. In total thirty-three different model names are mentioned. The most popular are Eulerian models (CAMx with 8 citations and CHIMERE with 11), CALPUFF is cited 6 times in our sample, but finally also traffic models are included (IMMIS, PROKAS and OSPM) with more than 5 citations. The many different models that are used today are a clear indication that no standard reference model currently exists. It is also interesting to note that in many AQPs, more than one model is used: three or more are used in more than 30% of the cases, while about 30% of the AQP refer to the use of two models and about 40% to a single model. Regarding research projects a single model is used in 45% of the cases, two in 15% and three or more in 40% of the cases sampled. In these projects CHIMERE is the most often used chemical transport model. It is important to stress however that in one reported case, no air quality model is used. Information about modelling methodologies is in general available since approximately 70% and 85% of the models referred to by the APPRAISAL database contributors are included in the EEA Model Documentation System, for AQP and RP, respectively.

If we analyze the responses in terms of model types, Eulerian models are the most used with 30 and 60% for AQP and RP, respectively (Fig. 5) which is not surprising since Eulerian modelling can be applied from the regional down to the local scale (see also Section 4). In the case of AQP, Gaussian plume and puff approaches represent about 25% in total while in RP they represent only 10% of use cases.

It is interesting to note that street canyon models (Vardoulakis et al., 2003) are not so frequently used (12% in AQP). It is probably due to the lack of proper input data at the adequate resolution, or due to the limited spatial coverage these models generally have. One can note that CFD models are rarely used in Europe even in research projects, probably due to their current limitation to idealized, stationary and very fine scale applications. Calculation of annual statistics therefore still remains a very challenging task for this type of models as shown in Parra et al. (2010) who attempted to estimate the concentration evolution from a series of steady state simulations for large time periods. With increasing computer power their importance might however increase in the future as they could progressively take on the role of the current generation of empirical or Gaussian models for local and street level modeling.

5. Scale and resolution issues

5.1. State of the art

Most modelling practices report the use of Eulerian mesoscale models to assess the impacts of AQPs (see Fig. 5). While these models are designed to capture regional to urban effects they are generally not fit to capture street scale phenomena. Indeed, while pollutant dispersion in the surroundings of densely built-up areas is governed by mesoscale wind flow systems, such as thermally induced valley winds, land and sea breeze circulations in coastal areas or channeled flow along valleys, the dispersion within a street in a densely built environment is dominated by the dynamic effects of urban structures on the turbulent transport within the urban canopy. In addition, other dynamical phenomena such as traffic induced turbulence and buoyant forces due to thermal exchange between the built environment and the surrounding air may also have an impact on the formation of the flow field dominating the dispersion of air pollution at this scale, particularly under low wind conditions, as shown by Santiago et al. (2015) who assessed the impact of the differential heating from walls, roofs and road on pollutant concentration.

In addition, traditional meso-to-local-scale emission inventories frequently lack the spatial information needed to resolve individual sources in the street-to-building scales as well as for accurately representing the pollutant dilution and transformation processes that occur at those scales.

Efforts to account for urban-scale effects in AQ models have in general evolved in three distinct directions:

a) Nesting/coupling of models: models with higher resolution but limited spatial coverage are coupled to lower resolution models but with larger spatial coverage (e.g. Tsegas et al., 2011).
b) Sub-grid modelling: sub-grid corrections are applied in the regional/local parameterizations within the lower computational layers, in an attempt to account for the specific characteristics of the urban canopy (e.g. Baklanov, 2004; Slørdal et al., 2008).
c) Downscaling methods: concentrations are re-distributed at finer resolution according to specific proxy variables like population or land use (e.g. Kiesewetter et al., 2013). Data fusion methods which take a variety of data sources such as ground based monitoring, air quality modelling, satellite

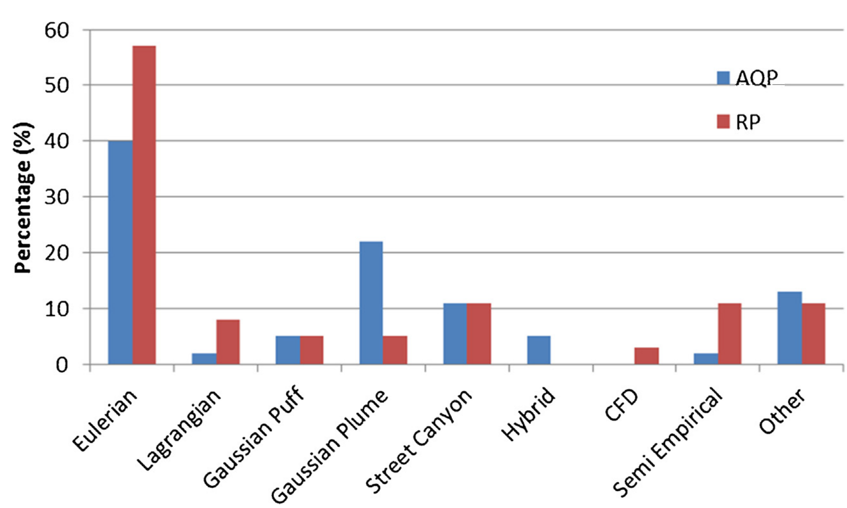

Fig. 5. Model types as used in AQP (blue) and RP (red). The hybrid classification refers to the application of a method based on numerical and statistical models. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

retrieved data and/or any other spatially distributed data relevant to air quality can also be used.

5.2. Current practices

In the questionnaires, spatial resolution has been used as the indicator for the spatial scale of the modeling approach (regional: 5–50 km; urban: 1–5 km; local: 1 km and street). Since at least 3–4 grid points are needed to resolve a flow structure, models with a resolution coarser than 3 km were classified as "regional scale" (5–50 km) while models with a resolution coarser than 500 m were considered as "urban scale" (1–5 km). The "local scale" (up to 1 km) models were those with a resolution between 500 m and 10 m and finally "street scale" models are those with a resolution in the order of meters.

In total 59 air quality studies were analyzed, each of them with up to 3 AQ models described, leading to a total of 177 different model setups (Fig. 6). Of these, 30% of the setups were for the regional scale, 30% at the urban scale, 15% at the local scale, and 15% at street scale. For the remaining 10% model setups no information was given on resolution or range of scales.

Although the majority of the AQP applications regard regional and urban scales (both greater than 30%), exceedances of air quality limit values occur at traffic induced hot spots to a large extent. Consequently some of the AQPs cope with street level (more than 20%) and/or local scale modeling (almost 15%).

As seen in Section 3, only 12% of the AQPs report on the use of highly resolved street canyon models. As mentioned above alternatives to explicit street canyon modeling exist and consist in extending regional/local scale model capabilities to account for sub-grid scale effects, either by means of effective statistical approaches or by explicitly implementing a variety of downscaling schemes. However in the majority of the cases (more than 80%) reported in the APPRAISAL survey, no additional model feature is included in the modelling approach to capture street effects, although these are keys to reproduce the concentrations and frequent exceedances at street locations.

The gap between current practices and the state of the art in the specific topic of downscaling is important. While some of the state of the art methodologies start to be applied in support to policy (e.g. Kiesewetter et al., 2013), they are yet seldom used in current AQP and even RP.

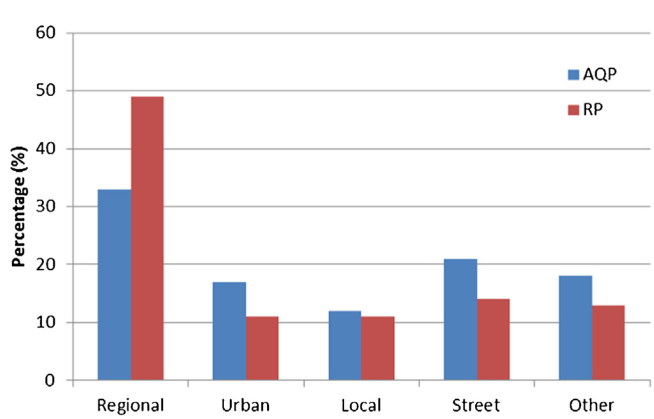

Fig. 6. Main scope for air quality assessment with respect to spatial scale for AQP (blue) and RP (red). Regional ranges from 10 to 50 km; urban from 1 to 5 km and local below 1 km. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

6. Input data: emissions, meteorology and boundary conditions

6.1. State of the art

The IPCC (2006) and EEA (2009) guidelines are available to set up emission inventories at the continental and national scales and constitute currently the standard, accepted methodologies. But at the urban and local scales, no such standards are currently available and projects rely on project specific inventories. Relevant information on desirable practice for compiling such emission inventories can however be found in the Forum for AIR quality MODEling guidelines (FAIRMODE, 2010) and in the Citeair2 INTERREG project report (Davison et al., 2011). Among other points, these two reports mention the importance of favoring bottom-up approaches detailed at the spatial and temporal resolutions adequate for the modeling purposes. While a bottom-up approach relies mostly on local activity estimates collected over the area of interest (e.g. traffic counts for road segments in a city), the top-down approach distribute emission totals (country or region, e.g. derived from total fuel sales) spatially according to gridded proxies (e.g. population, land use . . .). The FAIRMODE and Citeair2 INTERREG reports also stress the importance of disaggregating emissions sources to a sufficiently detailed level to allow relating the emission totals to the measures considered in the AQP.

Accuracy of the emissions is also crucial. The uncertainties in emission inventories mainly result from uncertain emission factors and can be highly variable between different emission source sectors (e.g. Zhao et al., 2011, Karvosenoja et al., 2008; Guevara et al., 2013). In air quality modelling applications considerable additional uncertainty may arise from the spatial distribution of the emissions, i.e. how well the location or distribution of emission sources is known and how well it can be incorporated in the models at an appropriate resolution.

The initial and boundary conditions also play an important role, especially for meteorology and particularly for ozone.

Meteorology is another key factor impacting concentrations. While in the 1990s, the global scale meteorological forecast system outputs (e.g. NCEP and ECMWF) were used for regional studies, forecast systems largely evolved since then and mesoscale models are now suitable and available. Indeed, these mesoscale models fit better the fine resolutions used in current modelling practices with their better resolved land cover data and turbulence parameterizations. Some of the mesoscale models account for urban meteorology and its impact on wind and temperature (see Chen et al. (2011) for a review of the urban developments introduced in the WRF meteorological mesoscale mode). At a very fine scale, diagnostic models are often used based on observations and allow, among other, a more accurate spatial distribution of the concentration levels.

6.2. Current practices

The APPRAISAL data base allows for an evaluation of current practices concerning model input data, i.e. emission inventory, meteorological data and boundary conditions.

From the responses received, it is noted that the scale and resolution of the emission inventory in general is in good agreement with the scale and purpose of the study (and model). Studies at the national level generally use emissions from national official inventories while studies that focus on the regional or urban (1–5 km), to local (up to 1 km) and street level scale use project specific emission data. In principle the resolution of the modelling system should be in line with the resolution of the emission inventory but among the 59 questionnaires, 5 applications seemed to use an emission resolution not adapted to the geographical zone for which the study was intended.

In emission inventories, emissions are classified among their sources. In the APPRAISAL questionnaire, the Selected Nomenclature for reporting of Air Pollutants (SNAP code) is used. This nomenclature was originally developed by the EEA's European Topic Centre on Air Emissions (ETC/AE) and is common for emission inventories used as model inputs. In this nomenclature source-emissions are classified among three levels of details:

- macro-sectors (SNAP level 1, e.g "energy transformation sector"); it exists 11 different macro-sectors,
- sectors activity (SNAP level 2, e.g. public power) which are a disaggregation of macro-sectors activity,
- activity levels (SNAP level 3, e.g "combustion plants ≥ 300 MW (boilers)") which are a disaggregation of sectors levels.

For each disaggregation level, more details can also be added with definition of fuel specification.

Emission inventories with disaggregation to the sector activity and activity levels are most commonly used (Fig. 7). Together they cover one half of the questionnaires. Only 10% of the studies use a macro-sector disaggregation level. A combination of different level of disaggregation is often used. Fuels specification is used in more than 50% of the cases. According to the database, there is no relation between the category disaggregation level and the spatial scale of the study.

Concerning the approach used to set up the inventory, a combined approach using both a bottom-up and top down methodology is most common (58%). This is not surprising as official national and regional inventories are usually constructed using this complementary approach. A top-down approach alone is used in few cases (8%) while bottom-up approaches alone represent about 22% of the cases. For the studies using a bottom-up approach, a majority of them have created a project specific emission inventory over a small area. Urban, local and street level studies represent more than 80% of the studies using a bottom-up approach.

A large majority (74%) of the AQ models are run with meteorological data from global or meso-scale meteorological models depending on the scale of the study. Meteorological measurements are mainly used for urban or more local studies performed with Gaussian (52%) and street canyon (24%) models. At the meso-scale, the meteorological models MM5 (Grell et al., 1994), WRF (Skamarock et al., 2007) and ECMWF are the most widely used in Europe (with more than 5 citations in the questionnaires each).

Similarly to meteorology, initial and boundary conditions are mainly provided by larger scale simulations through nesting.

7. Measurements for model evaluation and data assimilation

7.1. State of the art

Measurements may be used in two ways in air quality assessment studies:

- to evaluate performances (comparison of modelling with monitoring data)
- to improve the model accuracy (combination of monitoring and modelling data using data assimilation techniques or simplified methods).

In the first case it is important to ensure that the model is fit for purpose and that a threshold level of quality is reached for a given application, especially if in support to policy. The FAIRMODE forum is currently reviewing and proposing new model quality objectives to support this evaluation task. Two of the topics under discussion in FAIRMODE are the choice of appropriate statistics for the quantification of model performances and the accounting of uncertainties in the model evaluation.

Regarding the use of monitoring data in combination with modelling, techniques range from mapping (off-line interpolation of measurements, or model-observation residuals), nudging (on-line mapping used to modify the model simulation along time) to advanced spatio-temporal methods such as 3D or 4D-variational data assimilation and ensemble methods. Kriging of surface concentrations (e.g. Fedorov, 1998), kriging and optimal interpolation of model-observation residuals (e.g. Blond et al., 2003; Kumar et al., 2012; Candiani et al., 2013) are the most frequently used methods to quickly produce air pollution maps (also called analyses). 4D-var methods (Elbern et al., 2000) are advanced data assimilation methods fulfilling time consistency through physical and chemical laws as constraints. Variational and ensemble methods such as Ensemble Kalman filters (van Loon et al.,

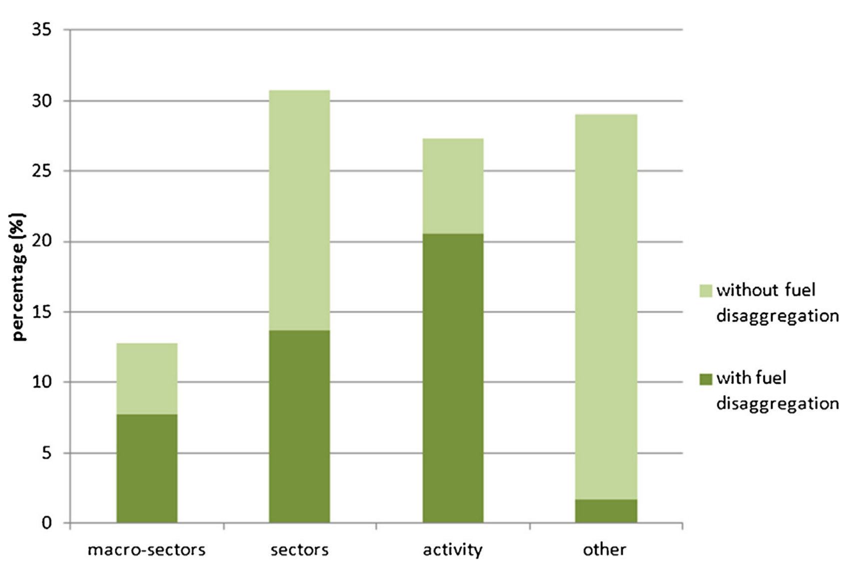

Fig. 7. Disaggregation level used in AQP and RP as reported in the APPRAISAL database.

2000) are also regularly used for forecasting applications. A review on data assimilation is given in (Lahoz and Khattatov, 2010).

In both aspects (evaluation and data assimilation), spatial representativeness of the monitoring data remains a crucial issue. Monitoring data is always an observation at a point location whereas modelled values are in most cases volume averaged estimates. Currently, a well-defined methodology for assessing the spatial representativeness of monitoring data is not available, and it is up to the model user to select monitoring data which are suitable for the specific modelling application.

Model evaluation becomes an issue when combining model results with measurements, as in this case measurements lose their independent status. The most widely used approach consists in separating the available monitoring dataset into assimilation and validation data sets.

7.2. Current practices

In about 85% of the assessment studies reported in the APPRAISAL database, measurement data is used as complementary information to the modelling results. In more than half of those studies measurement data are used for model evaluation. Apart from model evaluation, measurement data are used for post-processing (20%), boundary conditions of local or street canyon models (13%), model calibration (9%) and/or data assimilation (4%).

The measurement data used for these applications are collected by monitoring stations in an automated network in 75% of the cases whereas measurement data from specific field campaigns are used only in 20% of the studies. This clearly points out how important continuous and automated monitoring network data are as complementary information to model applications.

8. Conclusions

In this paper we summarized the outcome of the APPRAISAL project with respect to the review of current IAM practices. The database constructed in this project has been used as main support to this analysis. This database was populated on the basis of a survey sent throughout Europe, to which 59 responses from 13 countries were received. For each of the investigated topics a first section dealt with the review of the state of the art while a second part was devoted to the analysis of the current practices identified in the APPRAISAL database. In the phase of design and assessment of Air Quality Plans, integrated assessment modelling is currently mainly performed through scenario analysis while more elaborated methods using optimization methods still remain in the research projects. Regarding the main IAM component, i.e. air quality modeling, there are many different models reported to be applied but none is a standard or preferred modelling tool. However, most of these models are documented and information is available for most of them through the EEA model database. The variety of models applied for AQP is not limited to variability across groups, as indicated by the number of different modelling tools applied within a given group. Indeed more than half of the sampled cases report the use of more than one model for their AQP. This is clearly related to the fact that at present no single model is capable to describe properly all relevant spatial scales of the air pollution phenomena from the regional down to the street level scale.

Most respondents are aware of scale issues in designing and assessing the impacts of their AQP. This is reflected in the consistency of the input data they use, in particular emissions. The methodology and resolution of emission inventories indeed generally fit well the modelling purposes and scale of interest of the AQP. Emissions are however reported to be the most uncertain input in the IAM modelling chain and the consistency between emissions used at different scales remains a major concern.

A recurring theme is the challenge posed by local scale modelling and especially the integration with larger-scale results. This is certainly true for IAM tools which remain few at the local scale. The lack of a proper downscaling procedure in most of the studies however calls for an improvement in this respect with the aim to improve the accuracy of street level assessments.

Regarding model evaluation, it is troublesome to note that in 15% of the reported cases, measurement data are not used at all, even not for model evaluation. The issue of integrating measurements when using a scenario analysis as well as the need of a proper evaluation methodology for models results was also pointed out by the respondents of this APPRAISAL survey.

Generally differences between state of the art and current practices remain important in all fields, as are differences noted among current practices. These differences call for an increased harmonization of modelling practices in the EU.

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