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VITO
D2.3 Air quality assessment and planning, including modelling and measurement

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1 Summary

The methods used for air quality assessment and planning are reviewed in this deliverable based on the results of the APPRAISAL database. The document describes the different modelling tools that are used to define the Air Quality Plans and in research projects. Special attention is paid to how results are obtained at different scales and how these are combined. The emission input and other input for air quality modelling are considered as well as the combined use of measurements and modelling results.

Version History

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Summary of Changes

Version	Section(s)	Synopsis of Change
0.1	All	Initial version with some parts still missing
0.2	All	Revision and completed document
0.3	All	Changed structure
1.0	All	Some minor changes

2 Contents

1 Introduction

The APPRAISAL Project is a FP7-ENVIRONMENT Coordination Action funded by the European Commission within the call FP7-ENV-2012-one-stage, Grant Agreement number 303895. The project started officially on June 1st 2012 and initial activities started shortly after.
One of the main purposes of APPRAISAL is to perform an overall review of the methodologies, from simple (e.g. scenario approach) to more comprehensive ones (e.g. full cost-benefit analysis) that are used in different countries to compile local and regional air quality plans. To this end in work package 2 *'Review and gaps identification in Air Quality and Health Assessment methodologies at regional and local scale'* activities were established aiming to address this particular reviewing objective. More in particular a questionnaire and database structure were defined in which the WP2 work was broken down into five subjects which are included in the database structure: (i) synergies among national, regional and local approaches, including emission abatement policies; (ii) air quality assessment, including modelling and measurements; (iii) health impact assessment approaches; (iv) source apportionment; and (v) uncertainty and robustness, including Quality Assurance / Quality Control (QA/QC).

The present deliverable concerns the review of the results in the APPRAISAL database with respect to 'Air quality assessment and planning, including modelling and measurement'. For this topic, 5 subtopics were identified: (a) Integrated assessment modelling tools and methodology, (b) Air quality modelling tools, (c) Resolution and downscaling, (d) Emissions and other model inputs and (e) Measurements and modelling. For each of these 5 subtopics we first present the state of the art. Then we analysed the information in the database and compared this with the state of the art to determine the limitations of the current methodologies and what the key areas for further research are. Finally some recommendations are given with respect to the Air Quality Directive.

2 Current state of the art for assessment and planning tools

Integrated Assessment Modelling (IAM) tools and methodology

In literature different methodologies are described to evaluate alternative emission reductions:

- scenario analysis (Vinuesa et al., 2003 ; Vautard et al., 2007) that is performed by evaluating the effect of an emission reduction scenario on air quality, using deterministic modelling simulations;
- source-apportionment (Belis et al., 2013), that has the aim of finding which are the sources of emissions that mainly contribute to air pollution concentrations; this technique is described in more detail in a companion project deliverable;
- cost-benefit analysis (Moussiopoulos et al., 2005) that monetizes all costs and benefits associated to an emission scenario in a target function, searching for a solution that maximizes the objective;
- cost-effective analysis (Amann et al., 2012; Mediavilla-Sahagun and ApSimon, 2003) that has been introduced in order to take into account the high uncertainty affecting the quantification of costs and benefits of non-material issues;
- the multi-criteria approach (e.g. ELECTRE approaches, as in Vlachokostas et al. (2011)), used to explicitly consider multiple criteria in decision-making environments;
- the multi-objective analysis (Guariso et al., 2004; Carnevale et al., 2007), that performs a selection of the efficient solutions, considering in a vector objective function all the targets regarded in the problem, but stressing conflicts among them.

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). GAINS model considers the co-benefits of simultaneous reduction of air pollution and greenhouse gas emissions. It has been widely used in international negotiation (as i.e. in the 2012 revision of the Gothenburg Protocol) and is currently applied to support the 2013 air policy review. GAINS can be run both in the “scenario analysis” mode, and in the “optimization mode”. Through the “optimization mode”, GAINS identifies cost-optimal allocations of emission reductions in order to achieve specified deposition levels, air pollutants concentration targets, or GHG emissions ceilings.

Some experiences at national level have been developed, starting from the EU GAINS level methodology. Two well-known implementations are i.e. RAINS/GAINS-Italy (D’Elia et al., 2009) and RAINS/GAINS-Netherlands (Jaarsveld et al. 2004), in which the RAINS/GAINS methodology has been adapted and replicated at the national level. Another national level implementation is the FRES model (Karvosenoja et al., 2007), developed at the Finnish Environment Institute (SYKE) to assess, in a consistent framework, the emissions of air pollutants, their processes and dispersion in the atmosphere, effects on the environment and potential for their control and related costs. An additional important initiative at national level is the PAREST project, in which emission reference scenarios until 2020 were constructed for PM and for aerosol precursors SO_2, NO_x, NH_3, NMVOC, for Germany and Europe (Builtjes at al., 2010). The ROSE model (Juda-Rezler, 2004) has been developed at Warsaw

University of Technology (WUT) for Poland. ROSE is is an effect-based IAM comprised of a suite of models: an Eulerian grid air pollution model, statistical models for assessing environment sensitivity to the sulphur species and an optimisation model with modern evolutionary computation techniques.

At the urban/local scale a few integrated assessment methodological models have been developed and applied (see e.g. Carnevale et al., 2012; Zachary et al., 2011; Vlachokostas et al., 2009; Mediavilla-Sahagun and ApSimon, 2003). In RIAT (Carnevale et al., 2012) the main goal is to compute the most efficient mix of local policies required to reduce secondary pollution exposure, in compliance with air quality regulations (e.g. EU directives), while accounting for characteristics of the area under consideration. RIAT solves a multi-objective optimization, in which an Air Quality Index is minimized, and constrained to a specific emission reduction implementation budget. An important feature of RIAT is the use of nonlinear air quality models to link emissions and concentrations over the study domain. The Luxembourg Energy Air Quality model (LEAQ) (Zachary et al., 2011) integrated assessment (IA) tool focuses on projected energy policy and related air quality (NOX, VOC, O3) at the urban and small-nation scale. The tool has been developed initially for the Grand Duchy of Luxembourg, but is flexible and could be adapted for any city with sufficient information concerning energy use and relevant air quality. The UKIAM model (Oxley et al., 2003) has been developed to explore attainment of UK emission ceilings, while meeting other environmental objectives, including urban air quality and human health, as well as natural ecosystems. Nested within the European scale ASAM model (Oxley et al., 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 volumes and composition.

Air quality modelling tools

In the last two decades atmospheric modelling has experienced important improvements. Nowadays, a large variety of modelling systems and options exist, from simpler to more complex ones, covering from global / regional scales to urban and street level scales. In the context of integrated assessment chemical transport models have become widely used tools for assessing the effectiveness of control strategies adopted by regulatory agencies.

A comprehensive listing of air quality models used in Europe can be found in the EEA (2011b) Model Documentation System (MDS). In addition, European Cooperation in Science and Technology Action 728 (COST 728, 2011) has developed a model inventory that provides information on a large number of mesoscale air quality and meteorological models.

In general one can distinguish the following model types:

- Gaussian and non-Gaussian parameterised models
- Statistical models
- Obstacle-resolving fluid dynamical models (CFD)
- Lagrangian particle models
- Eulerian chemical transport models
- Lagrangian chemical models

State-of-the-art models include the online chemical transport models which allow the study of feedback interactions between meteorological and chemical processes within the atmosphere. Examples of such models are WRF-CHEM or the European COSMO-ART (Knoth et al, 2011) and COSMO-MUSCAT (Wolke et al., 2004) models. An important trend is the inclusion of atmospheric chemistry modules in earth system models, in which the links between climate, atmospheric composition and the biosphere can be studied.

Another phenomenon is the use of obstacle resolving computational fluid dynamical (CFD) modelling in air quality studies (Vos et al., 2012). Such CFD applications are currently still limited to idealised, stationary and/or very small scale applications but with ever increasing computer power their importance is due to increase for air quality modelling where these tools could take on the role of the current generation of empirical or Gaussian models for local and street level modelling or complement the results from the latter type of models.

Resolution and downscaling

It has been long recognised that in a typical urban environment, transport and diffusion of air pollutants are governed by processes that occur between the micro/local and mesoscales, while their levels may also be affected by transformation processes and by long-range transport, i.e., processes occurring at the regional scale. Pollutant dispersion in the surroundings of densely built-up areas will be 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. On the other hand, within the densely built environment of modern cities at a street scale the dispersion of air pollution 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 produced 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. On an equally significant level, emission inventories as used in traditional meso-to-local-scale modelling frequently lack the spatial information needed in order to resolve individual sources in the street-to-building scales as well as for accurately representing the pollutant dilution and transformation processes that occur in these scales.

There is also the remaining problem of the accuracy and representativeness of the emissions values which are dependent on the space and time resolutions. For example, the traffic emission of a main road, is considered to be a continuous line source. This is correct if the scale i.e. the time and space resolution is not too big (roughly for space and time resolution of 1x1km^2 x 1 hour).

In view of these limitations, it is of no surprise that direct comparisons of local measurement data with results from a number of mesoscale model simulations under “current state” scenarios in urban areas demonstrate a limited validity of such models as a basis for AQ assessments. This experience has led to the realisation that urban AQ assessment based on meso-to-local scale modelling approaches need to be extended by taking into account sub-grid effects, either by means of effective statistical approaches or by explicitly implementing a variety of downscaling schemes.

Efforts to account for urban-scale effects on AQ models have in general evolved in three distinct directions in regard to the chosen approach for linking the different scales of assessment. These may be separated into three major types, namely sub-grid modelling, downscaling methods and nesting/coupling of models.

Sub-grid modelling
In this type of approach, sub-grid corrections are applied in the mesoscale parameterisations within the lower computational layers, in an attempt to account for the specific characteristics

of the urban canopy (Baklanov, 2004). This addresses the inclusion of 'sub-grid' models within gridded Eulerian models. A common approach is the placement of Gaussian type line or point source models, e.g. 'Point in grid' or PIG models, inside a gridded Eulerian model. This is a similar concept to nesting but in practical terms the methodology is different as it goes from one type of model, Eulerian, to another, Gaussian. This will provide improved resolution in areas where large gradients occur and can provide, in the case of PIG models, an improved description of the dispersion and chemistry of a plume before placing the pollutant into the Eulerian grid. An implementation of such an approach can be seen in the operational multiscale model system AIRQUIS-EPISODE (Slørdal et al, 2008). A stochastic fields method has been proposed by Cassiani et al (2009) for incorporating sub grid scale emission heterogeneity in mesoscale atmospheric dispersion models. The aim here is to incorporate the effect of sub-grid scale emission heterogeneity on concentration fluctuations calculated in a typical mesoscale model, by assimilating sub-grid emission variability as probability density function of the emissions.

Downscaling methods

Downscaling methods that redistribute concentrations according to specific parameterisations may also be used within Eulerian grids. The use of nested models is often called 'dynamic' downscaling but other types of downscaling will involve the use of parameters that are available at higher resolution than the model itself, e.g. population and land use, and these will be used to redistribute the concentrations within grid squares (TSAP report 9, 2013). Downscaling may provide higher resolution concentration fields or it may provide statistical information of the grid that can be used for further assessment. As previously described data fusion methods take a variety of data sources such as ground based monitoring, air quality models, satellite retrieved data or any other spatially distributed data relevant to air quality (such as altitude, land use or emissions) and combines these data in some (hopefully optimised) way to produce an air quality assessment. One of the most straightforward methods is single or multiple linear regression, where model concentrations, and perhaps other supplementary data, are fitted to the available observations using least squares optimization (e.g. Horálek et al., 2007; Denby and Pochmann, 2007). Regression methods may also be used to estimate the background concentration (EC working group, 2000) or multiple linear regression may be applied to the individual model source contributions in order to adjust the modelled field (Laupsa et al., 2009). In addition to the regression and residual interpolation methods outlined above there are also a number of more complex statistically based methods for achieving data fusion. Such methods include those described by Fuentes and Raftery (2005), Gelfand and Sahu (2009) and McMillan et al. (2009). These methods combine Bayesian approaches with a range of statistical methods. Optimal interpolation, which can also be used as a data assimilation method similar to 2-D var, may also be used as a data fusion method (Flemming et al., 2002). A combination of these approaches has been applied in the frame of the EC4MACS project (TSAP report 9, 2013) in which the EMEP 28-km resolution model has been downscaled to the urban 7 km scale with the CHIMERE model and is further downscaled to even higher resolution using population proxies. Finally, the street level concentrations are obtained through a combined box-model approach fitted on available measurements.

Nesting/coupling of models

This is the nesting of higher resolution models of limited spatial coverage, in lower resolution models of larger spatial coverage. Recent research has focused in refining and further developing methods for extending nesting approaches or coupling individual models in different scales, taking into consideration interactions between the various scales aiming to assess the effect of such interactions on urban air quality (Martilli, 2007). This is typically the case where Eulerian models are applied, both meteorological and chemical transport models. One way nesting means that information from the larger scale model is passed to the smaller scale model in one direction only, as boundary conditions for that model. Two-way nesting means that the high and low resolution models pass information in both directions (Tsegas et al, 2011). Nesting can have many levels, all the way from global models to local street level models. Examples of state-of-the-art integrated multiscale models include the MECTM system that couples the macro-scale model CTM2 with the air flow model METRAS (Lenz et al, 2000), the multiscale French SUBMESO system for calculating the dispersion and transport-diffusion-transformations of reactive pollutants within an urban area (Penelon et al, 2010), the EMEP Eulerian photochemistry model coupling regional scale models to global modelling systems (EMEP, 2003) and the US EPA's Models-3 Air Quality modelling systems which provides the software framework for utilizing different models in a single case study (Binkowski et al, 2003).There are a number of examples of nested modelling systems and models using downscaling or sub grid models, as shown in

Table 1.

Table 1 Chemical transport models or modelling systems used in Europe that link different scales

Model/ System	Comments/description	Links to documentation, validation and intercomparison studies
THOR	**Nested modelling system going from global model (DEHM) to urban (UBM) to street level (OSPM) concentrations**	http://thor.dmu.dk
MATCH	**Chemical transport model capable of one way nesting from regional to urban scale**	Robertson et al. (1999)
CAMx	**Chemical transport model capable of one way nesting from regional to urban scale**	ENVIRON (2009)
MODELS3/ CMAQ	**Chemical transport model capable of one way nesting from regional to urban scale**	http://www.cmaq-model.org/
AURORA	**Chemical transport model capable of one way nesting from regional to urban scale**	Mensink et al. (2001)
EMEP	**Chemical transport model capable of one way nesting from regional to urban scale**	http://www.emep.int/
TCAM	**Chemical transport model capable of one way nesting from regional to urban scale**	Carnevale et al. (2008)
CHIMERE	**Chemical transport model capable of one way nesting from regional to urban scale**	http://www.lmd.polytechnique.fr/chimere/ Vautard et al. (2005)
RCG REM-CALGRID	**Chemical transport model capable of one way nesting from regional to urban scale**	http://www.geo.fu-berlin.de/met/ag/trumf/RCG/
WRF-CHEM	**Chemical transport and meteorological model capable of two way nesting between regional and urban scales**	http://cprm.acd.ucar.edu/Models/WRF-Chem/
SIMAIR-road	**Combines regional (MATCH) with local scale and (OSPM)**	http://www.smhi.se/en/services/professional-services/Environment/simair-road-1.7647 Omstedt et al. (2011)
AIRQUIS-EPISODE	**Contains sub-grid Gaussian models for line and point sources in an urban scale Eulerian grid**	www.airquis.com

Emissions and other model inputs

For setting up emission inventories at the continental and national scales the IPCC (2006) and EEA (2009) guidelines are currently the standard, accepted methodologies.

For air quality modelling at 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 be found in the guidelines of the subgroup 3 of the FAIRMODE work group 2 on 'Urban emissions and Projections' (FAIRMODE 2010) and the report on 'Integrated Urban Emission Inventories' of the Citeair2 INTERREG project (Davison et al.,2011). Based on the information from the APPRAISAL database and these reports a state of the art urban emission inventory that can be used for air quality modelling in the context of air quality planning should have the following characteristics:

- A bottom-up approach is preferred in general, with usually a control using a top-down approach.
- Emissions should be disaggregated to the level of detail required to relate the emission totals to the measures considered in the air quality plan.
- The spatial resolution of the emissions should be aligned with the resolution of the model.
- Hourly measured emissions are preferred. If these are lacking source-specific temporal patterns should be adopted as much as possible.
- If different emission inventories are combined, the consistency should be checked and different approaches should be reconciled.
- The emission information must be in agreement with the specific requirements of the modelling system: speciation, vertical discretization, plume rise calculation, release point location information.
- Uncertainties on the emission values have to be known or evaluated for each source type
- Uncertainties on emission values have to fit with the sensitivity of the model used and with the purposes of the whole study.

The problem of the accuracy of the emission values is also crucial. If the uncertainties on the emission values are larger than the differences between the scenario and the base case, the differences in the modelled concentration results will not be significant. The same problem will arise if the concentration changes due to emission changes are within the uncertainty of the model.

Concentrations are also very sensitive to meteorological variables. A direct error concerning the meteorological fields used has a more or less direct and linear impact on concentrations (Minguzzi et al., 2005). In addition, the selected horizontal resolution of a data set has a large impact on results (Valari and Menut, 2008).

In the 1990s, the global scale meteorological forecast system outputs, such as NCEP and ECMWF were used for regional studies, mainly applying interpolations to re-grid the mesoscale data fields. In recent years, the forecast systems largely evolved: they now use a mesoscale model, driven by global meteorological fields, but more adapted to the fine resolutions and with more relevant land cover data and turbulence parameterizations. In Europe, the American mesoscale meteorological models MM5 (Grell et al., 1994) and WRF

(Skamarock et al., 2007) are the most widely used because they are easy to implement and to change. One important point in CTM and mesoscale models is how they can take into account urban meteorology and its impact on wind and temperature. Urban conditions are usually represented by using a very simple roughness approach (change in surface roughness and heat flux), but it may not be particularly accurate in predicting or assessing the flow and dispersion at street scale. Few modelling approaches have been proposed to take into account the interaction of urban areas on the atmosphere in mesoscale meteorological models (COST 732 reports ; Masson, 2000 ; Martilli et al. 2002 ; Kikegawa et al. 2003 ; Britter et Schatzmann 2007; Salamanca et al., 2010). Solazzo et al. (2010) proposed a simple scheme for estimating spatially-averaged mean wind speed and the urban heat island over a selected neighbourhood area in Lisbon, Portugal. The results show the capability of the urban model to provide more accurate mean wind and temperature profiles with limited computational resources. A summary of references to urban meteorological modules, modelling results, and discussions can be found in Mahura and Baklanov (2010). Another issue, is to represent meteorological conditions in areas close to complex orography. In that case, nudging of the mesoscale model with observations seems to be a suitable technique to correct the overestimation of the wind intensity by meteorological models.

At a very small scale, diagnostic models are often used based on observations. The use of urban meteorological diagnostic models or Large Eddy scale models will allow, among other, a better spatial distribution.

Measurements and modelling

Today there is general agreement that the consistency of air quality models should be checked against measurements.

Within the FAIRMODE initiative, WG2-SG4 is devoted to developing a procedure for the benchmarking of air quality models. The final aim of this working group is to arrive at a standard procedure that can be used to intercompare model results, that can aid the judgment of models' quality and promote good practices. Two of the topics under discussion in WG2-SG4 that are important for model evaluation are the choice of appropriate statistics for model performance quantification and how to account for model and observation uncertainty in the model validation.

By far the most widely used methods for combining observations with model results are (residual) kriging (Blond et al., 2003), optimal interpolation methods (Kumar et al, 2012; Blond et al., 2004) or other interpolation methods which are most often applied 'off-line' in that they take model output and post process the results. Online assimilation methodologies that integrate information from the measurements with the model results during the model calculation include the variational methods of 2D-, 3D- and 4D-var (Elbern et al., 2000) or ensemble methods such as Ensemble Kalman filters (van Loon et al. 2000).

An issue to consider when combining model results with measurements is that of validating these combined results. Two possible approaches in that case are leaving-one-out validation or dividing the measured data into an assimilation and a validation data set. This is an issue also treated by Kiesewetter et al. (2013).

3 The database

This deliverable corresponds to the second topic addressed in the database: Air quality assessment and planning, including modelling and measurement. The questions in the second topic were classified according to the following aspects of drafting an Air Quality Plan or conducting a research project.

Which tools are used:

- for Integrated Assessment Modelling (IAM) and what is the methodology used for selecting an efficient abatement strategy?
- for air quality modelling?

How are results at different scales obtained and combined?
Which inputs are used in the air quality modelling?
How are measurements used in combination with the air quality modelling?

In addition to these questions the respondents were asked to comment on the limitations or weaknesses of the Air Quality Plan or research project they reported on.

4 Results from the database

During the analysis of the answers given through the interviews, we distinguished the answers that were given for “air quality plans” (AQP) from those that related to “research projects” (RP) (

Figure 1). The rationale for this is that the AQP will be representative for current practice while the RP might have a broader scope since there are no such formal constraints that have to be obeyed and that may go beyond what is state of practice.

Whilst AQPs are a consequence of air quality assessment and limit value exceedances detected in connection with this, RPs might have a broader scope since there are no such formal constraints that have to be obeyed and that may go beyond what is current practice.

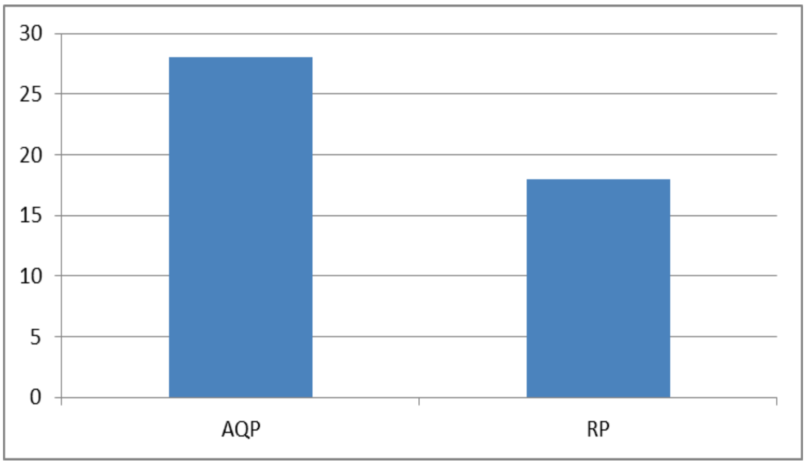


Figure 1: Number of Air Quality Plans (AQP) and research projects (RP) in the database.

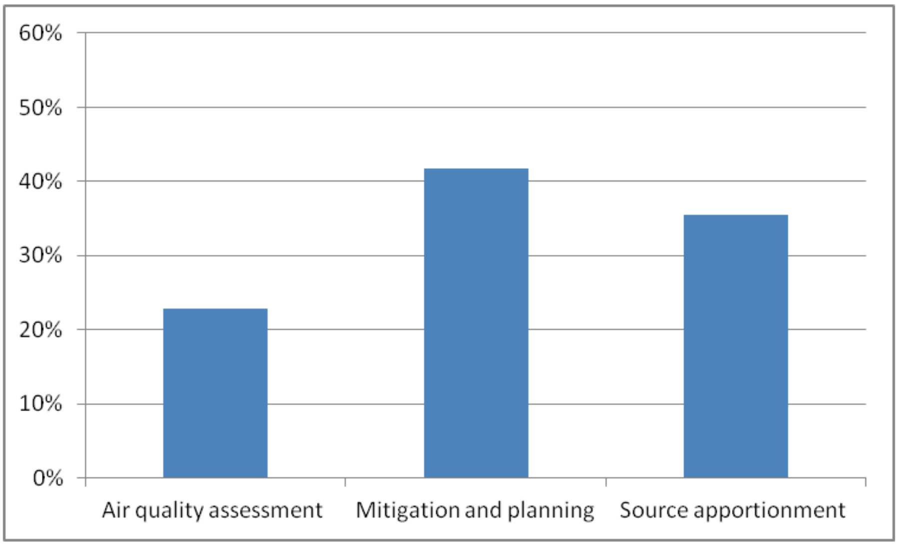
In the next chapters, we cover the results obtained from the data base for the following 5 aspects:

- Integrated Assessment Modelling (IAM) tools and methodology
- Air quality modelling tools
- Resolution and downscaling
- Emissions and other model inputs
- Measurements and modeling

Integrated Assessment Modelling (IAM) tools and methodology

From the question on the “modelling purpose” of the work, it is possible to notice (

Figure 2) that IAM is mainly used for defining mitigation measures and planning. The main difference between the AQP and RP is related to the “source apportionment” technique, that is mainly used in “air quality plans” (35% of the AQP), and less in “research projects (roughly 10% of the RP). This is maybe related to the different purpose of AQP and RP in general: a RP is not necessarily aimed at identifying causes of exceedances.



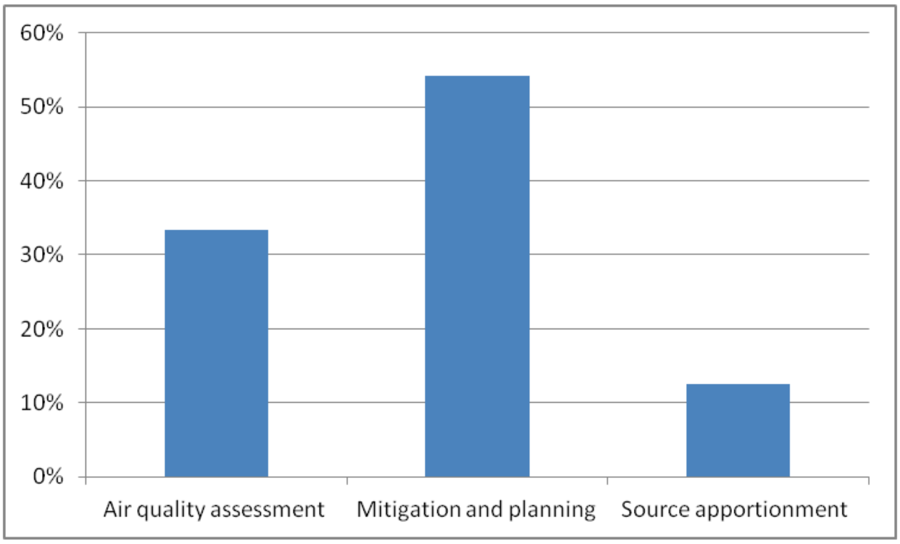
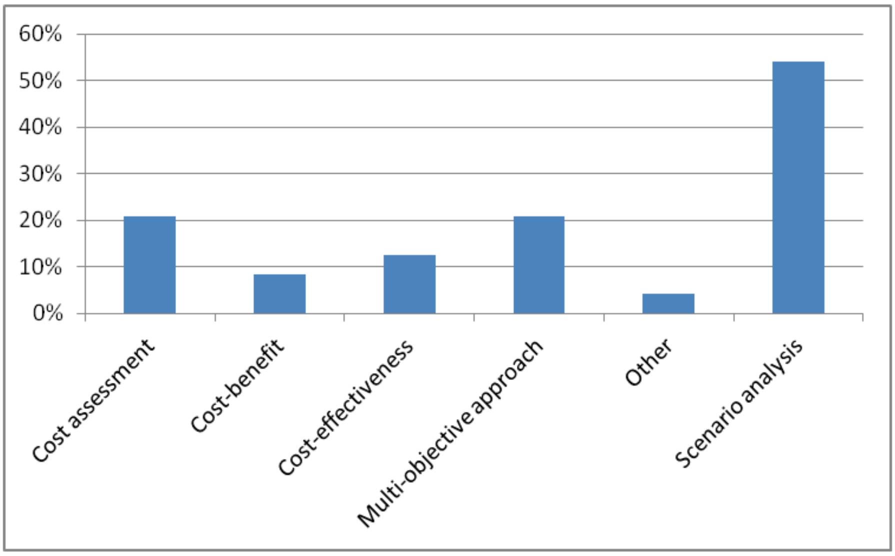


Figure 2: modelling purpose (in % over the total) of "air quality plans" (top) and "research projects" (bottom).

"Scenario analyses" are most frequently used among the IA methodologies that were considered (

Figure 3), both in AQP (more than 50% of the cases) and RP (roughly 30% of the cases) implementation. The more complex approaches, based on Cost-Benefit, Cost-Effectiveness and Multi-Objective are used a bit more often in the research projects (about 5% more).

Such more complex methodologies, in which optimization algorithms are implemented, cannot embed full 3D deterministic multi-phase modelling systems for describing the nonlinear dynamics linking precursor emissions to air pollutant concentrations because of their computational requirements. They therefore rely on simplified relationships for describing the relationship between the emissions and the air quality which are called source-receptor (SR) relationships for which further details are provided in Annex 1.



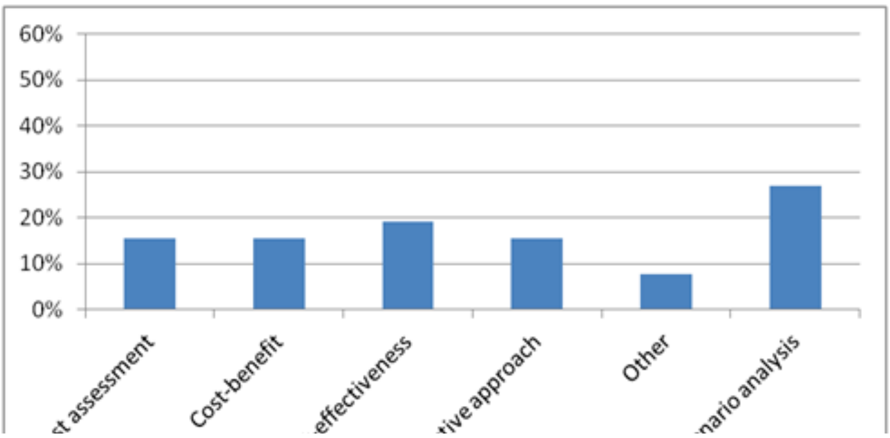


Figure 3: Integrated Assessment methodology (in % over the total) of "air quality plans" (top) and "research projects" (bottom).

In terms of the Design of Experiment required to identify these SR, the majority of approaches apply the OaT (Once at a Time) approach for the design itself in which one varies one emission at a time, and measures the variation in the concentration or effects at one site. In some (few) cases "factor analysis" in which the impact of an emission and its interactions with another factor are considered simultaneously or a "statistical based" approach that is based on global sensitivity indexes are used. The number of scenarios considered in the Design of Experiment is only in the case of more complex research projects more than 50 (Figure 4). Also the number of years considered is in 70% of the AQP limited to a single year.

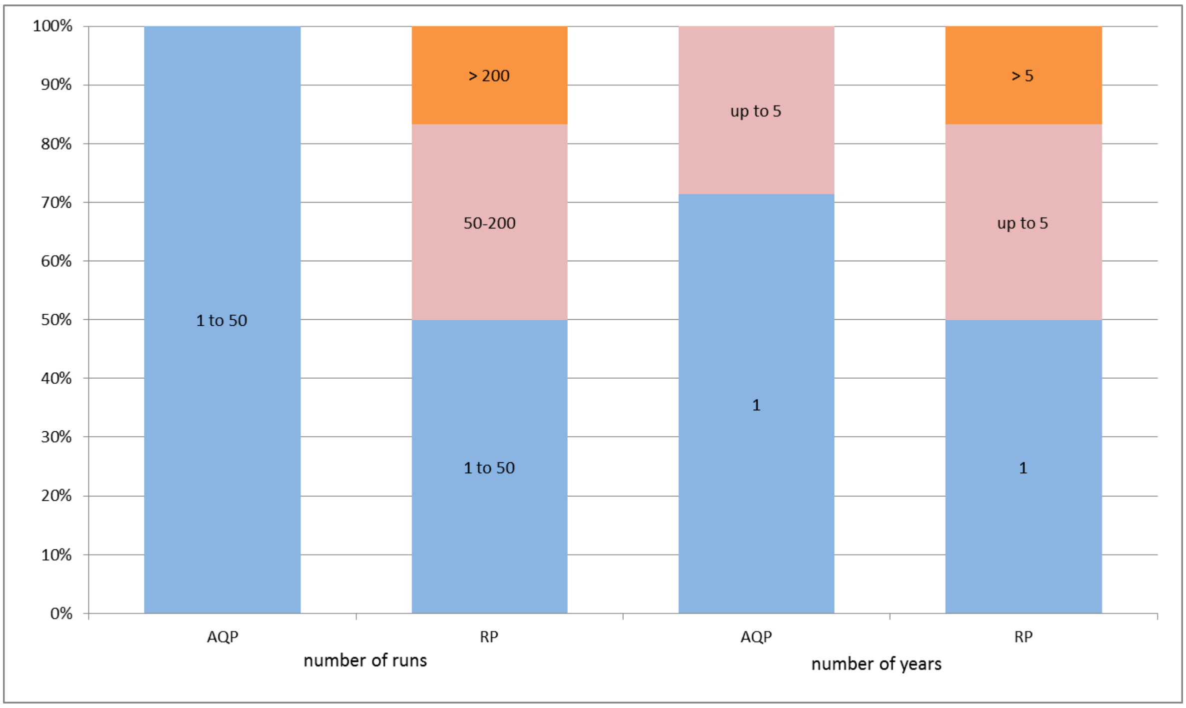


Figure 4: Number of AQ modelling simulations required to identify SR (runs) and number of meteorological years considered for air quality plans (AQP) and research projects (RP).

The IA indicators considered, as shown in

Figure 5, are similar in 7both the “air quality plan” and “research project” cases. Usually the main focus is on “population exposure”, followed by “internal and external costs”, and then by the “other” indicators.

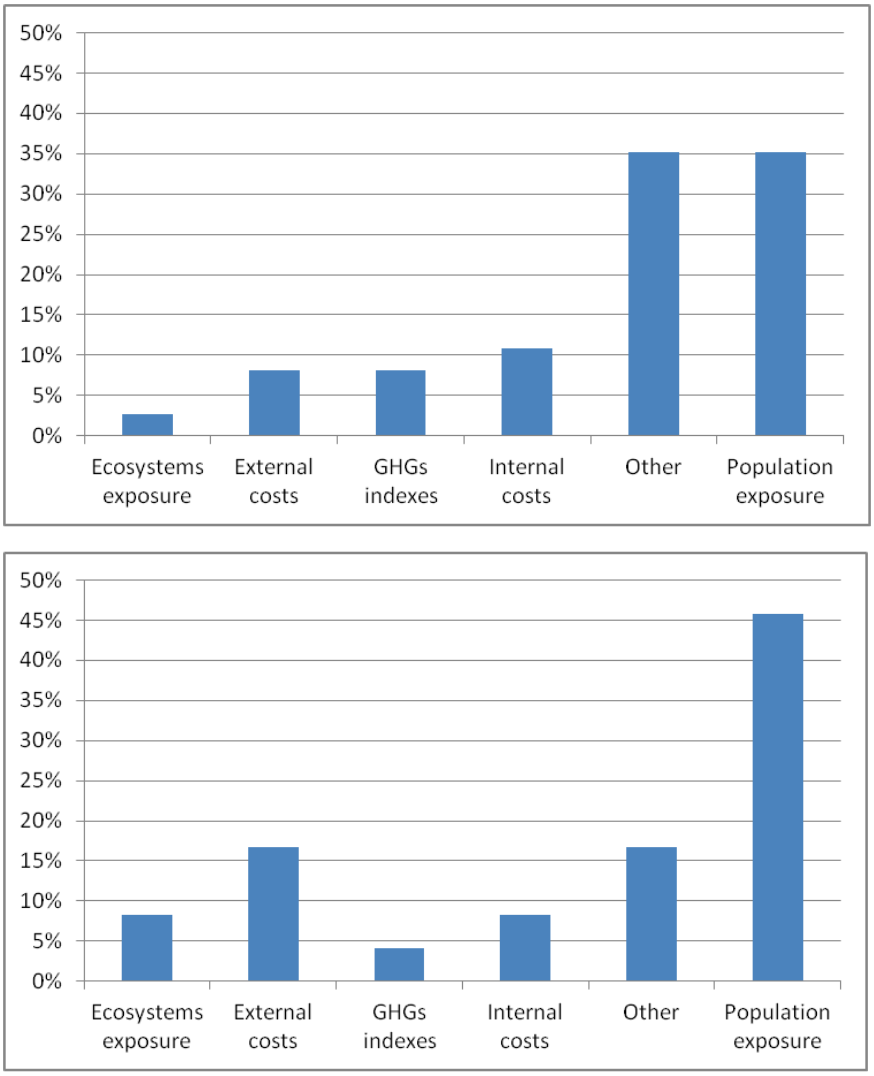


Figure 5: IA indicators (in % over the total) in the case of “air quality plans” (top) and "research projects" (bottom).

Air quality modelling tools

According to the results from the database three or more models are used in 26% of the Air Quality Plans. About 30% use two models, 26% use one model, and 18 % do not use any kind of air quality model.

A large variety of air quality models were used in the different member states to develop Air Quality Plans. In total thirty-three different model names are mentioned. The most used were OSPM (4 x), CAMx (3 x) and CALPUFF (3x). The fact that a model name appears at most a few times is an indication that there is not really a standard model that is used by a large community. Table 1 lists the models reported in the Air Quality Plans.

Table 2: Models used to develop the Air Quality Plans and Research Projects
BE: Belgium, CY: Cyprus, DE: Germany, EL: Greece, FI: Finland, FR:France, LU: Luxemburg, PL: Poland, PT: Portugal, SE: Sweden

Model Name	Countries	AQP/RP	Model Name	Countries	AQP/RP
ADMS Urban	ES,FR	2 / 2	ISIS Kfz	DE	1 / 0
AURORA	BE	1 / 2	LOTOS EUROS	DE,NL	0 / 2
AUSTAL2000	IT,LU	1 / 2	MARS-aero	CY	1 / 0
CALINE4	EL	1 / 0	MISKAM	DE,FR	2 / 0
CALMET	IT,PL	1 / 3	Neural Network model	CY	1 / 0
CALPUFF	IT,PL	3 / 2	OPS	NL	0 / 1
CAMx	IT,PL,PT	3 / 5	OSPM	BE,FI,ES	4 / 1
CAR	NL	0 / 1	OFIS	EL	1 / 0
CAR-FMI	FI	1 / 1	PAL	EL	1 / 0
CHIMERE	BE,FR,IT,PT	3 / 5	PROKAS_B (open road)	LU	1 / 0
CMAQ	ES	2 / 0	PROKAS_V (street canyon)	DE,LU	2 / 0
COSMO/MUSCAT	DE	0 / 1	RAINS	FI	1 / 0
ECMWF	BE	1 / 1	REM-CALGRID	DE	2 / 0
EURAD	DE	0 / 1	SIRANE	FR	1 / 0
FARM	IT	0 / 1	SPRAY/MICROSPRAY	IT	0 / 1
GAINS	SE	0 / 1	STREET	FR	1 / 0
HYSPLIT	ES	1 / 0	TCAM	IT	1 / 0
IFDM	BE	2 / 1	The Air Pollution Model (TAPM)	PT	1 / 0
IMMIScpb	DE	1 / 1	UAM-V	EL	1 / 0
IMMISluft	DE	1 / 1	URBAIR	PT	0 / 1
IMMISnet	DE	1 / 1	VADIS	PT	0 / 1

Approximately 70 % of these models used to draw up Air Quality Plans are included in the EEA Model Documentation System, which has been developed with the aim of providing information and guidance to any user of air pollution models in selecting the most appropriate model for a specified application. Considering the models' classification (

Figure 6) Eulerian chemical transport models are clearly the most used in Air Quality Plans (40%) followed by Gaussian plume models (22%). The main features included in the models are transport (25%) followed by turbulence and chemistry (both 24%).

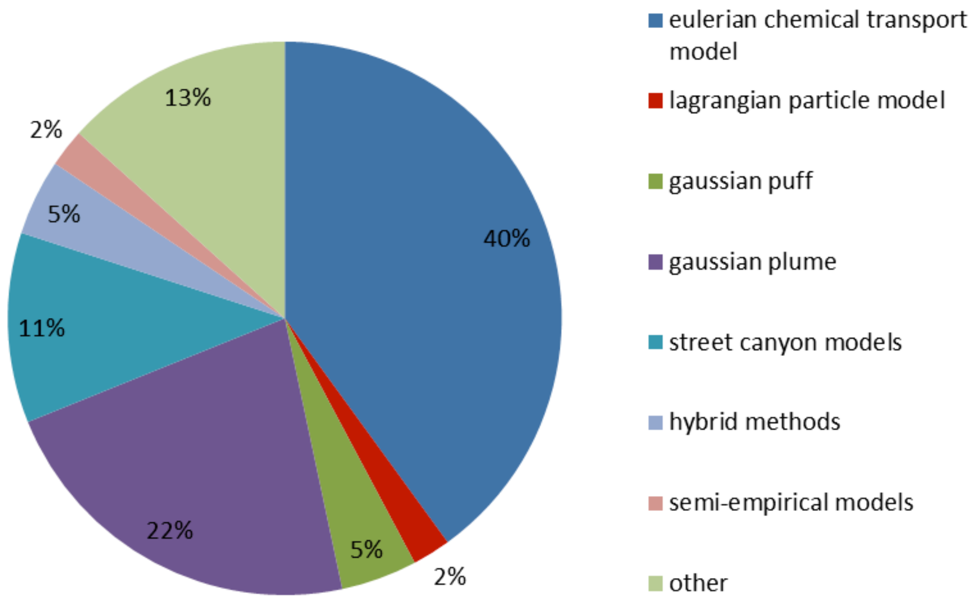


Figure 6 Model classification of the models used in the Air Quality Plans reported.

Results for the Research Projects and activities other than Air Quality Plans are shown in Figure 7. From the analysis of the Research Projects and activities other than Air Quality Plans whose information was included in the database, and which use one or more Air Quality model(s) to perform Air quality assessment and planning (20 Projects / Activities), it follows that:

- 45% use only one Air Quality model, 25% two AQ models and 30% used three or more AQ models;
- the majority of models (57%) can be classified as Eulerian chemical transport models and from those, 86% are included in the EEA Model Documentation System (CHIMERE is the most used model); 8% were Lagrangian particle models (all included in the EEA MDS), 5% were Gaussian puff models (CALPUFF, not included in the EEA MDS) and another 5% Gaussian plume models (all included in the EEA MDS), 11% were street canyon models (all included in the EEA MDS);
- one of the studies (3%) used an obstacle resolving fluid dynamical model (included in the EEA MDS);
- in total 81% of the models are included in the EEA Model Documentation System.

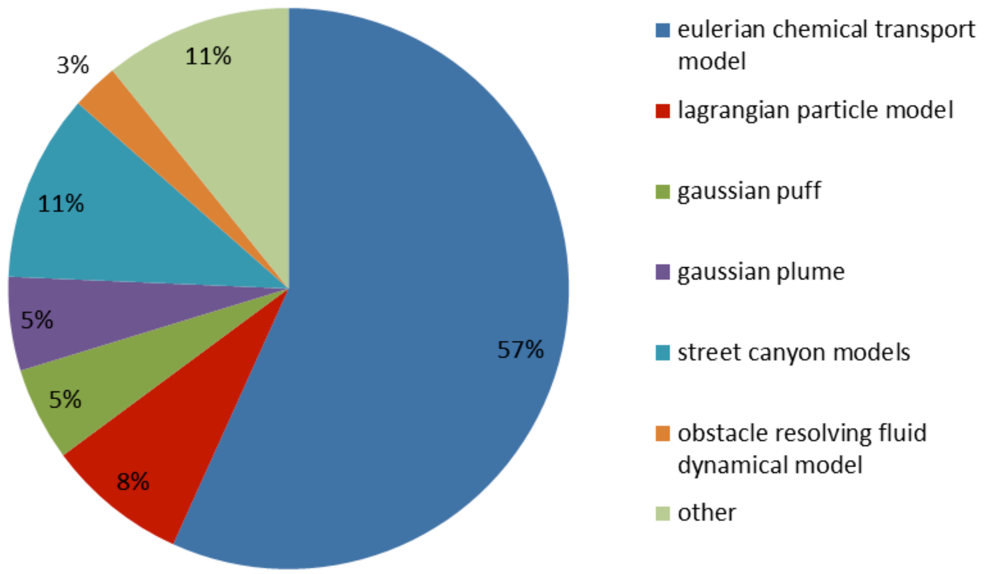


Figure 7 Model classification of the models used in the Research Projects and activities other than Air Quality Plans reported.

Resolution and downscaling

In the analysis of the questionnaires, in order to determine the scale of the modelling study, priority has been given to the resolution used, since it is the key parameter that determines the smallest scale that can be resolved. To determine the largest scale, information on the modelling domain would be needed, which was not available. The information provided for “range of scales” was considered only when no information on the resolution was given. 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 500m were considered as “urban scale” (1-5 km), “local scale” (up to 1km) models were those with a resolution between 500m and 10m and finally “street scale” models are those with a resolution in the order of meters.

In total 53 air quality studies were analysed and up to 3 AQ models can be described in each questionnaire, leading to a total of 106 different model setups. Of these, 38 (36%) of the setups were for the regional scale, 14 (13%) at the urban scale, 12 (11%) at the local scale, and 18 (17%) at street scale. For the remaining 23% model setups no information was given on the resolution or the range of scales. Considering the subclass of the studies done to support Air Quality Planning (29 projects and 57 models), 19 (33%) were at regional scale, 9 (16%) at urban scale, 7 (12%) at local scale, and 12 (21%) at street scale, with the remaining 18% with no information on resolution. The 18 Research projects analyzed used 35 models, with the following repartition: 17 (49%) at regional scale, 4 (11%) at urban scale, 4 (11%) at local scale, 5 (14%) at street scale, and the remaining 14% with no information. The “other type of activity” subclass (6 studies, and 14 models), has 2 regional (14%), 1 urban (7%), one local (7%), and the remaining with no information (64%).

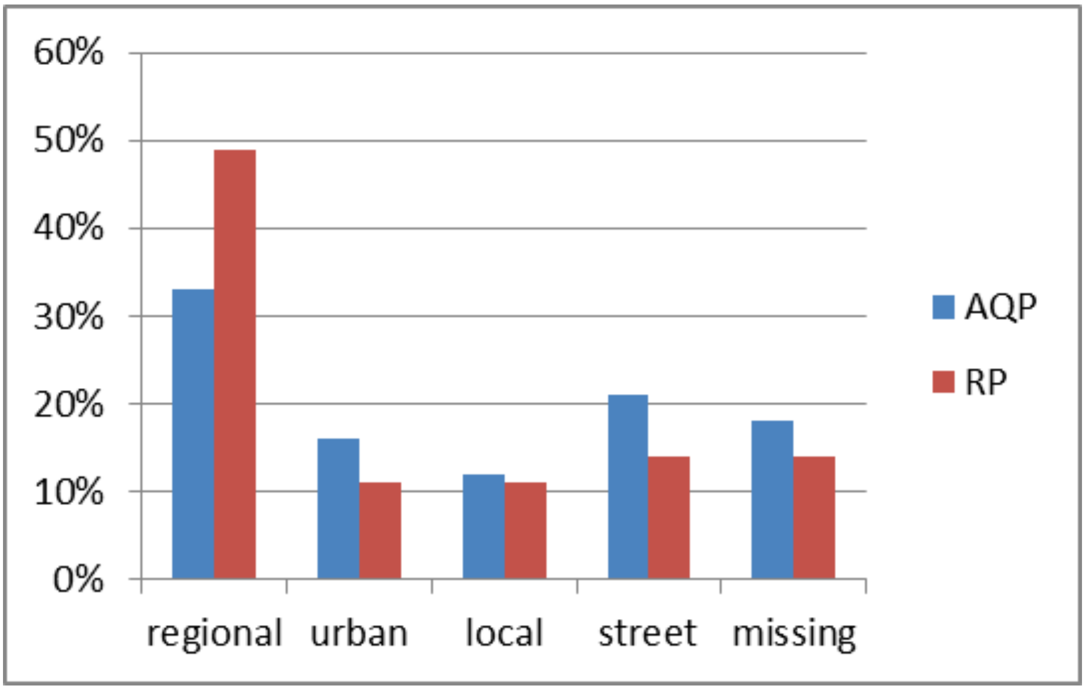


Figure 8 Scales of the modelling in the air quality plans and the research projects.

Emissions and other model inputs

Concerning the model input data, the data base provides information on the emission inventory, the meteorological data and the boundary conditions that were used.

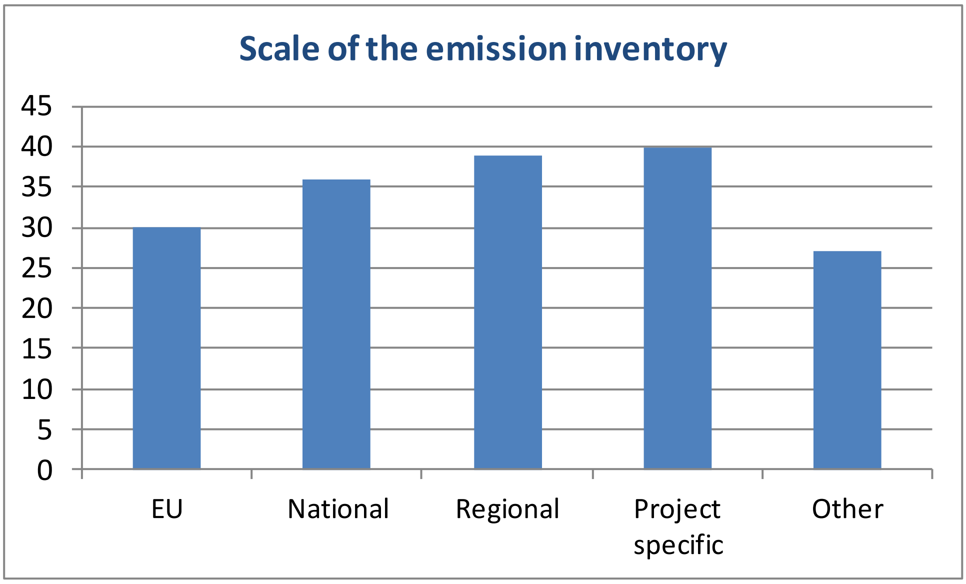


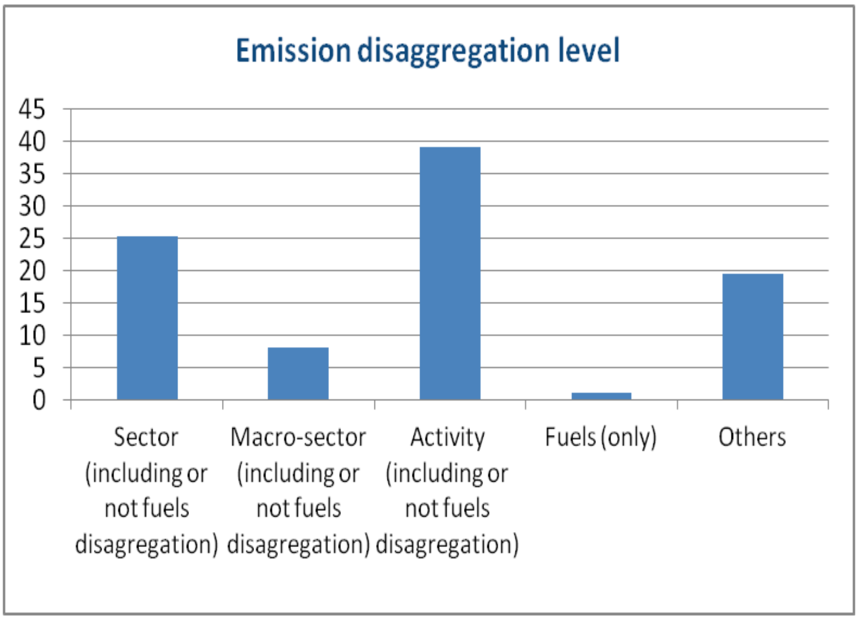
Figure 9 Scale of the emission inventories (in number of responses)

Comparing the scale of the emission inventory (Figure 9) with the scale of the study (and the model) shows that, overall, emission inventory resolutions are adapted to the studied geographical zone. Studies at the national level generally use emissions from national official inventories while studies that focus on the regional or urban (1 to 5 km) scale use regional official inventories and/or project specific emission data. Local (up to 1 km) and street level studies generally use project-specific emissions. The EU (EMEP) emissions were also used for studies focusing on a large scale (50 km) or studies where scale is not mentioned. Among the 54 questionnaires, only 5 seem to use an emission resolution not adapted to the geographical zone for which the study was intended. The latter are urban scale studies, in which a CTM with a resolution of 3 to 7 km is combined with a national emission inventory where normally a regional or project-specific inventory should be used. The project-specific emission inventories used in about 38% of the cases are also difficult to value as the questionnaire was not intended to reach this level of detail.

Emission inventories with disaggregation to the activity levels (e.g. Combustion plants ≥ 300 MW (boilers)) are most commonly used (

Figure 10). Only 8% of the studies use a macro-sector disaggregation level and 25% a disaggregation to a sector level (e.g. public power). Fuels disaggregation is also used in 25% of the cases. According to the database, there is no relation between the disaggregation level and the spatial scale of the study.

Concerning the approach used in setting up the inventory (Figure 10), a combined approach using both a bottom-up and top down methodology is most common (36 %). 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 14% of the cases and bottom-up approaches represent 30% of the cases. For the studies using a bottom-up approach, a majority have created a project specific emission inventory for a small area (urban, local or street level). However, some answers indicate bottom-up approaches when using EU or national emissions inventories or when focusing on regional levels, which seems unrealistic. Without these unrealistic answers, a bottom-up approach is used by 24% of the respondents. Urban, local and street level studies represent more than 80% of these studies using a bottom-up approach.



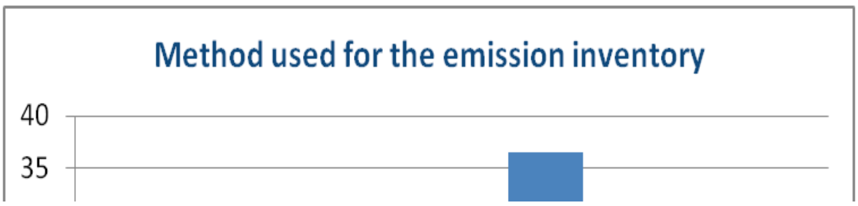


Figure 10 Method and disaggregation level in emission inventories (in % of the non-blank responses)

A large majority of the AQ models are run with meteorological data from a global or mesoscale meteorological model depending on the AQ model scale (Figure 11). Meteorological measurements are mainly used in street canyon modelling (50%) and urban scale modelling. The spatial resolution of the meteorological models is never higher than 4 times the AQ models spatial resolution. A list of meteorological models used in AQP is presented in Table 3.

The initial and boundary conditions are mainly provided by a larger scale model. As for the meteorological models, the use of measured data as initial and boundary conditions is mainly done at a small scale (street level, local and urban scales represent 83% of the cases).

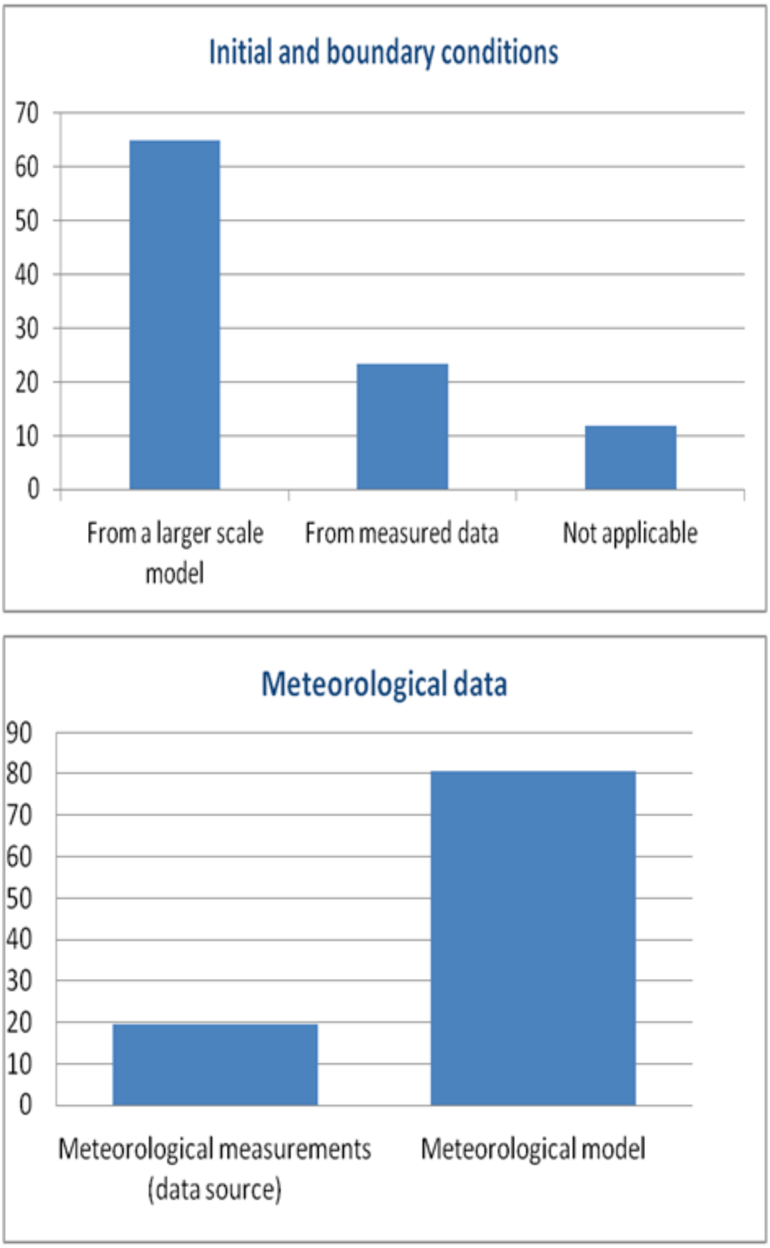


Figure 11 Origin of the meteorological, initial and boundary conditions data (in % of the non-blank responses).

Table 3 Meteorological models used in AQ plans

Model name	Number	Type of model
ECMWF	6	Global 3D Meteorological Model
WRF	8	Mesoscale 3D meteorological model
MM5	5	Mesoscale 3D meteorological model
ARPS	1	Mesoscale 3D meteorological model
CALMET	4	Diagnostic model
SIRANE	1	Diagnostic model
TAPM	1	Mesoscale online AQ Model
MISKAM	1	Urban scale 3D Meteorological Model
TRAMPER	3	Mesoscale 3D meteorological model (diagnostic)
MIUU	1	Mesoscale 3D meteorological model
COSMO	2	Mesoscale online AQ Model
RAMS	1	Mesoscale online AQ Model
MEMO	1	Mesoscale 3D meteorological model
TALdia	1	Diagnostic model

Measurements and modelling

In about 60% of the assessment studies reported in the APPRAISAL database, measurement data is used as complementary information to the modelling results. In 88% of those studies, measurement data is used for model evaluation. Apart from model evaluation, in about 1/3 of the studies measurement data is also used for other purposes (Figure 12) such as model calibration, the boundary conditions of local or street canyon models, post processing and data assimilation.

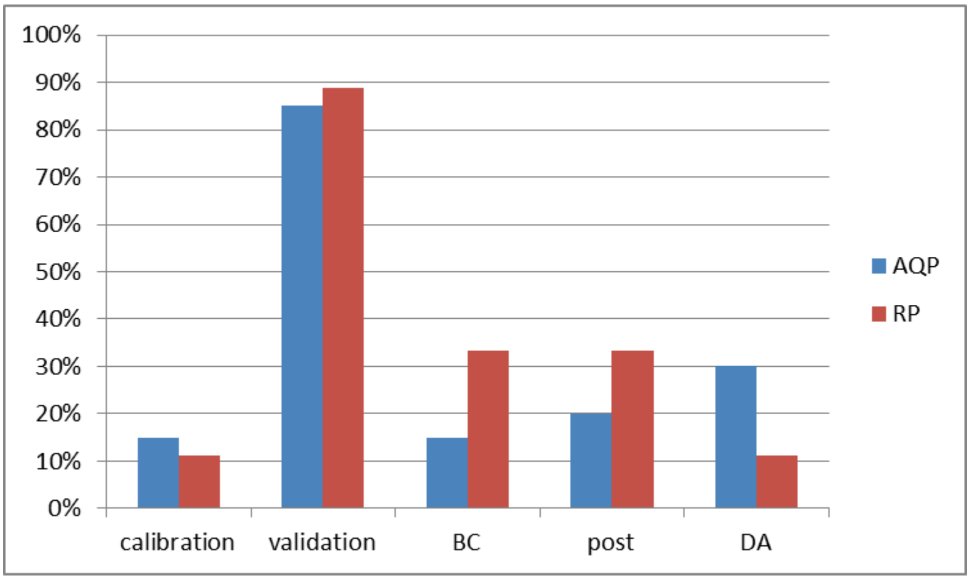


Figure 12 Use of measurement data in air quality plans (blue) and research projects for calibration, validation/evaluation, boundary conditions (BC), post processing (post) and data assimilation (DA)

Measurement data used in these types of applications is in 3/4 of the cases collected by monitoring stations in an automated network and only in 25% of the studies, measurement data from specific field campaigns is used. This clearly points out how important continuous and automated monitoring network data is as complementary information to model applications. Limitations of the current assessment and planning tools and key areas for future research and innovations

Integrated Assessment Modelling (IAM) tools and methodology

1. How to incorporate non-technical measures?

Non-technical measures or energy efficiency measures (EM) are measures that reduce anthropogenic driving forces that generate pollution. Such measures can be related to behavioural changes of people (for instance the use of bicycles instead of cars for personal mobility, or the reduction of the heating in buildings) or to technologies that reduce the energy demand by decreasing the fuel consumption (for instance the use of high efficiency boilers, building thermal insulation).

Regional policies range from incentives or regulations on end-of-pipe technologies (technical

measures, TM), to energy efficiency measures (EM). These last options are often fundamental at a regional level to reach EU air quality standards. In fact, in some cases, end-of-pipe measures are adopted at a “higher” decision level (European or national), and so the regional authorities need to extend their “possibility of intervention”, exploring EM options.
However there are still a lot of challenges in using these measures in IAM. Future research will need to focus on:

- models and methodologies to incorporate EM in IAM, in combination to TM;
- estimation of costs and efficiency of EM;
- uncertainty associated with EM.

2. How to include the effect of non-linearity’s in the SR relationships?

Usually an IAM applies linear functions to model the link between emissions and concentrations. If it is true that this linear simplification works at European/national scale, at regional level or at higher spatial resolutions as demonstrated by GAINS however it is important to properly model nonlinear dynamics in the formation and accumulation of secondary pollution. Future research will need to underline the influence of non-linearities in IAM, focusing also on proper “Design of Experiments” methods, on one hand to maximise the information used to identify SR relationship and on the other hand for practical reasons to limit the number of Chemical Transport Model simulations required to derive these SR relationships.

3. Limitations to the available emission inventories

To compute emission reduction scenarios and policies, it is necessary to combine emission inventories and TM/EM databases. Such data are often provided by different authorities that can implement various methodologies and assumptions, for example on emission classification, spatial scales, emission factors, etc. This poses the issue of data consistency. Future research should focus on methods and tools to harmonize emission and measure datasets.

4. Local/ street scale IAM

Different models are designed and implemented to approach different spatial scales (from regional, to local, to street level). Future research should study how to integrate these different scales and to build an IAM system able to connect different "scale-dependent" approaches, and to model policies from regional, to local, to street scale.

5.Greenhouse gases issue

In the frame of the "Europe 20-20-20" programme, it is important to analyse the synergies between air quality and climate change interventions, at regional scale. Air Quality and Climate Change issues, characterized by different dynamics both in the time and space dimension and under the responsibility of different decision makers that define policies at different scales and with different planning horizon, should be described by a multi scale/multi dynamics comprehensive modelling system. Future research should address new methods to integrate multi scale/multi dynamics IAM to jointly deal with AQ and Climate Change.

Air quality modelling tools

Notwithstanding air quality models nowadays are used quite regularly there are still several processes that require a better description within the models including:

- aerosols: In general air quality models tend to underestimate particulate matter (PM) concentrations significantly while at the same time exceedances for PM are of greatest concern from a health perspective. Further research is required to improve modules for describing windblown dust, resuspension and the formation and fate of secondary organic aerosols. Significant scientific uncertainty also remains regarding the relative strengths of the sources of major components of fine PM, especially organic carbon and metals/dust.
- chemistry: Substantial uncertainties in gas-phase and aqueous-phase chemistry mechanisms remain including key inorganic reactions, aromatic and biogenic reactions and aqueous-phase chemistry. Future research might also include stratospheric chemistry as the spatial domain for air quality models increases when climate applications are considered.
- deposition: The exchange processes with the surface should be further improved considering for example surface bidirectional exchange (ammonia, mercury or polyaromatic hydrocarbons) or the interaction with vegetation.
- better coupling between the physics (meteorology) and chemistry in the model. This is not only relevant for coupled air quality and climate change modelling but is important when moving to smaller scales (< 1km) where the meteorological models start to resolve turbulent eddies.

Applying models at the urban or local scale requires including specific local scale processes, but also taking into consideration the influence of the larger scale. This is a challenge that still needs to be worked on because common practices are mainly based on the application of mesoscale models to urban areas without the proper urban parameterizations, and Gaussian models that even with new developments to simulate urban areas still are limited.

The use of CFD models to simulate urban areas, forced by a mesoscale model, is a current research area, but with strong limitations because of the computer time demands. Currently it is still impossible to simulate a full one year period with this modelling approach without several simplifying assumptions. In the near future these limitation could be overcome as computer resources keep improving and this type of development should therefore be considered as a key research area, including the proper link between the mesoscale and the CFD model. For small scales (e.g., less than 1 km) where turbulent eddies begin to be resolved by the meteorological model, coupling of the chemistry and physics becomes a necessity.

Models' evaluation is inherent to all these developments and also to common modelling practice. There are several already reported and applied procedures to evaluate models (including models intercomparison exercises), but with different purposes and focusing on particular types of models and/or applications. There is enough information to provide a standardised evaluation protocol organised according to different modelling needs and characteristics. This protocol would be particularly important for applications within the AQD requirements and for stakeholders who need to trust model results to decide and to implement air quality improvement measures. FAIRMODE activities are addressing this challenge, but a stronger focus on the urban and local scales is needed, as well as preparing the protocol for the needed (and expected) future developments.

Resolution and downscaling

The information from the database clearly shows that people in charge of air quality studies feel that Regional scale air quality models are the most appropriate tool. This can be explained by two factors:

1. The fact that a significant amount of research on regional scale air quality modelling has been done in the last 20-30 years both in North America and Europe. Models like CMAQ, CAMx, CHIMERE, CALGRID driven by prognostic (like WRF, MM5, RAMS, ARPS, or COSMO) or diagnostic (CALMET) meteorological models have been thoroughly tested over a variety of cases. These models are considered reliable, they can be obtained easily, and they have a large community of users that can share experience and best practice.
2. The fact that the competences on air quality often belong to regional authorities that are, obviously, interested in the air quality over relatively large regions.

The second largest class of models used is represented by street scale models. These models parameterize the circulation in the canyon (e. g. OSPM, one of the most used), or explicitly calculate it (e. g. MISKAM). It is interesting to note that 10 out of the 18 studies that used these models, used boundary conditions taken from measurements. This means that the study was focused only on the evaluation of the impact of a change of traffic emissions in the street on the pollutant concentration in the same street. The remaining 8 studies, on the other hand, used boundary conditions from air quality models at a larger scale. In this case, street canyon models were used to downscale the concentrations computed by the air quality models at urban or local or regional scale, to street level.

The models used at urban scale are essentially the same models as those used at regional scale, but run at a higher resolution. This is something that must be done with care, in particular for the meteorological drivers, since at kilometer, or sub-kilometer resolution the turbulent length scales may be comparable with the horizontal grid size, and some of the assumptions on which the derivation of the PBL closures is based are no longer valid. Models that were run at local scale, are mainly Gaussian plume models that use measurements as meteorological driver or wind fields produced by meteorological models run at coarser resolution. In this way only the spatial heterogeneity in the emissions fields at local scale are resolved, but not the local scale flow features.

In terms of future lines of model development, the information collected in the database indicates that there is a need to develop more reliable models at urban and local scales, and to improve techniques to link the models at different scales, in order to better represent the two way interactions between the regional scale and the street scale (downscaling the pollutant concentration at street level, and up scaling the effect of the street scale flow features to the regional scale).

Emissions and other model inputs

In the database 70% of the respondents identified emissions as the main weakness of their modelling approach. This is particularly true for local resolution modelling. Indeed, as spatial resolution increases, there is a need to increase the resolution for the emissions accordingly. Almost all studies focusing on small scales point out this lack of comprehensive, accurate and up to date emission data for bottom-up emission estimation method. Regional official inventories may not be resolved enough in these cases and those studies often develop project-specific emissions with a bottom-up approach.

Another recurrent weakness highlighted in the database is the uncertainty and lack of data (activity, Emission Factor (EF)) for quantifying anthropogenic emissions for new technologies, in particular new energy sources and new vehicles. Examples are EF for LPG, LGN or hybrid vehicles or uncertainties in emissions for a new euro standard (EURO 6). A lack of data is also pointed out for NH_3 emissions and small-scale wood burning.

Since several decades, modellers are used to consider the input emission databases as adjustable parameters for their models, which prevents correctly assessing the uncertainty of emission inventories. The emissions issued from anthropogenic stationary combustion installations can be considered as the most accurate with an uncertainty ranging from 5% to 15% for the most common gaseous pollutants. Mobile and small residential combustion sources are less well known and the uncertainty can amount up to a factor 1. The main problems are however the biogenic and natural sources for which the uncertainty is known to be a factor of 0.5 to 8 due to a lack of data. (Jörß and Handke, 2010). The estimation of the uncertainty is itself very uncertain as there are very few studies are dealing with this topic (van Ardenne, 2002; van Gijlswijk et al., 2004; Werner et al., 2005; Werner, 2009).

Concerning meteorological models, a better use of urban modules in mesoscale models would benefit regional and more local studies and help to link models at different scales.

Measurements and modelling

Measured concentration levels contain valuable information which can be used as additional information to modelling results. In that respect, it is striking that in 40% of the reported studies, measurement data is not used at all, even not for model evaluation. This is clearly a point where air quality assessment reports and more specifically Air Quality Plans could be improved.

Apart from its intrinsic measurement uncertainty, monitoring data has the clear advantage that the true concentration levels are estimated with much more accuracy than model results can do. The main question which arises in IA applications is how these measurement data can be used most appropriately. After all, most of the model results in IA studies are dealing with future projections under certain policy options and by definition, no measurement data is available for this kind of future estimates.

A key solution to this problem is to use measurement data in combination with model results at least for the reference case of a recent year. This reference case is most often used as a starting point in the IA exercise and it seems essential to estimate at least the concentrations of the reference case as accurately as possible. This procedure is referred to as model calibration or data assimilation.

Discussion arises when this combined information has to be used for simulation of policy scenarios. In general, it is considered appropriate to use the corrections of the data assimilation scheme or the calibration factors as “relevant” information in the scenario runs. However, specific and well defined methodologies to do so, are not at hand. One possible approach is to assess the simulated concentration changes of a set of specific policy options in relation to the reference case/year. The resulting concentration changes (so called deltas) can then be applied on top of the calibrated or data assimilated concentration fields of the reference year. Such a procedure for accounting for concentration changes is also described in Kiesewetter et al. (2013).

However, at present it is clear that still more research is required in order to pin down appropriate methodologies to combine measurement data in a reference year with modelling results for future policy scenarios.

5 Contribution to the Air Quality Directive

According to the European Air Quality (AQ) Directive, Member States must annually report their AQ to the European Commission. This report can be based on modelling data if the concentration levels do not exceed the established lower assessment thresholds or on combining data from modelling and monitoring systems (supplementary assessment methods), if concentration levels are below the upper assessment threshold. For the remaining cases modelling techniques can be applied to provide additional information. On the other hand, there is no alternative to modelling for assessing the effectiveness of emission reduction measures in future years. Thus, modelling should become an essential part of air quality planning, though the primary requirement for assessing air quality near the limit values might be done further with measurements. Any such modelling based report should include a complete description of the model and the inputs used as well as an evaluation to quantify the reliability of the AQ assessment.

Integrated Assessment Modelling (IAM) supports the Air Quality Authorities in selecting efficient mitigation strategies by providing tools for assessing and solving air quality planning problems at different spatial scales. In general the European Directive 2008/50 currently does not specify what methodology is required to devise efficient measures. The contents of the template provided for reporting however indicate that this methodology should address the following:

1. Air quality assessment for the current situation: In which zones (location, type) are exceedances of the limit values of a pollutant observed and how large is the population that is exposed?
2. Source apportionment: Which are the main emission sources responsible for the pollution, distinguishing local and regional (trans boundary) contributions? With which accuracy is known the emission source base case?
3. Air quality assessment for future years or emission scenario’s:
    - What is the baseline level i.e. the concentration to be expected in the year when the limit value comes into force without any measures beyond those already agreed or implied by existing legislation.
    - Which measures are currently in place beyond those required by current legislation and what is their effect on the air quality?
    - Which additional measures are planned and what is their effect on the air quality?

The Directive recognizes that modelling can be used in combination with measurements to obtain a better representation of the spatial distribution: “Where possible modelling techniques should be applied to enable point data to be interpreted in terms of geographical distribution of concentration” (Article 6). As population density is not necessarily homogeneous within a zone, the air quality plan report could be improved by replacing the single values for the concentration and population within the zone in the report by a map showing the spatial distributions for the concentration and the population.

Source apportionment (SA) and air quality assessment for future years or emission scenario’s (topics 2 and 3) are activities for which modelling of some sort is an obvious choice if not indispensable. From the APPRAISAL database it can be concluded that today many different modelling tools exist that are being used both for SA and AQ assessment and that there is currently no obvious standard model that could be imposed as a ‘preferred’ model for each of the different scales and pollutants considered. Preferably however the model as a whole or at least its subcomponents should have undergone a scientific peer review or a report should exist in which the model has been submitted to a diagnostic analysis. As using an appropriate model is in itself no guarantee that model results are correct, it should also be required that the model results presented in the Air Quality Plan are accompanied by a description of the main model inputs (emissions, meteorology, accuracy or uncertainties of the data) and an evaluation report in which model results are compared to observed concentrations in line with the work done in the FAIRMODE community and as e.g. described in the guidance document by Denby et al. (2010).

Article 25 of the Directive deals with the problem of trans boundary air pollution. To be effective an Air Quality Plan should appropriately take into account the contribution of sources outside the zone considered in the plan. This is especially true for long lived and secondary pollutants and where the zone that is modelled is small as in local and street level models. In those cases larger scale modelling is needed to properly incorporate the effect of the boundary conditions or at least a sensitivity analysis should be required to quantify the importance of the boundary conditions. If results at different scales are combined, the consistency of the inputs used should be checked and care should be taken to account for differences between the models.

Another important issue for a proper model application when developing an AQP within the AQD which is currently not covered by the AQD, concerns the representativeness of the simulation period for air quality planning. Currently an AQP usually relies on the model results for a single meteorological year. This year is often the year for which the exceedances were observed that triggered the demand for an AQP in the first place but which is not necessarily a year that is representative for the time horizon of the AQP. An alternative could be to select a single year (or years) based on criteria (e.g. typical meteorological year, critical meteorological conditions year) that assure it represents the air quality for the time horizon of the AQP. Another option could be to use a longer multiyear meteorological period for the AQP modelling work. The latter could however well be impractical considering the increase in computer time required to model such long periods. In conclusion, it is necessary to account for meteorological variability in air quality modelling and IAM since meteorology is a constraint that influences the effectiveness of emission reduction measures to some extent, though meteorology is not the primary cause for air pollution. This is generally addressed for EU scale IAM studies (e.g. IIASA GAINS approach) but seems lacking at the regional/local scale, most probably due to the limited resources available.

Further fixing and specifying the reporting obligations for emissions on EU-level might improve emission data necessarily needed for air quality modelling and in consequence will improve modelling results for this part.

Annex XV of 2008/50/EC should be revised by clarifying the requirements and information needed to design air quality plans for improvement in ambient air quality like outlined here.

6 Summary

In deliverable 2.3 of the APPRAISAL project we have analysed the results of the APPRAISAL database with respect to 'Air quality assessment and planning, including modelling and measurement'.

In the first two chapters we presented the state of the art and analysed the database results both for the Air Quality Plans which were processed in the database as for research projects. In Air Quality Plans integrated assessment is currently mainly done through scenario analysis while more elaborate methods using optimization methods are still more in the research realm. For air quality assessment it was found that currently many different models are being applied and that there is currently no standard modelling tool but that most of these models that are used are included in the EEA model database. When assessing the air quality, the results of more than one model are being used in more than half of the cases and overall, the resolution of the emission inventory and other inputs are adapted to the studied geographical zone. This indicates that many people (but not all…) when assessing air quality and drafting Air Quality Plans are aware of scale issues at least to a certain extent. Concerning the use of measurement data it is troublesome that in 40% of the reported cases, measurement data is not used at all, even not for model evaluation.

The third part focuses on limitations of the current practice and areas on which further research is needed for the different subtopics that were identified for 'Air quality assessment and planning, including modelling and measurement'. A recurring theme in this part is the challenge that is being posed by local scale modelling and especially the integration of these local scale results with results at larger scales. This is certainly true for the integrated assessment tools which currently are still scarce when considering local scale integrated assessment. For local and street scale air quality modelling we currently see more and more applications of computational fluid dynamics (CFD) models but these are still limited to small modelling domains and require a lot of simplifying assumptions. It is also not obvious how these CFD results can best be combined with larger scale model results. The main weakness reported in 70% of the studies is related to the emission inventories. Also here the observation is that where at the European level standards such as the EMEP emission inventory are available these are still lacking when moving to local scale inventories and that the consistency between the emissions used at different scales is a major concern. Finally for measurements the question was raised how model results in scenario calculations can best be combined with observed values.

The final chapter of this deliverable is dedicated to the Air Quality Directive and addresses how the different tools that are available for integrated air quality assessment can and/or should best be applied to support the Directive as well as some issues which are currently not covered by the Directive.

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Annex 1 - Source-Receptor models

In IAM approaches implementing optimization procedures, full 3D modelling systems (*physically based models*) are substituted by more computationally efficient Source-Receptor models (*surrogate models*) that directly link the available decision variables to some relevant indicators.
It is worthwhile pointing out clearly the differences between physically based models and their surrogate ones:

Physically based model (PBM)	Surrogate model
The physically based model (PBM) reproduces (with a certain accuracy, given that epistemic uncertainty always implies bias and mis-specification) the physical process linking emission to concentration, in the most general case.	The surrogate model depends on the specific decision problem and links the available decision variables (emission control measures) to the air quality indicators, selected as expressive for the specific problem.
The PBM is mostly represented by a high dimensional set of (non-linear) partial differential equations mimicking the physical processes.	The surrogate model structure may vary, and largely relies on the necessity to reproduce or not the original model dynamics. In a non-dynamic case, when only few indicators have to be computed as functions of their system evolution, numerous approaches are possible (principal component analysis, polynomial, neural networks, support vector machines, …). The basic requirements are (i) sufficient computational speed and (ii) acceptable accuracy in reproducing the PBM results in assigned conditions.
The PBM is aimed to be general: can be applied to any (reasonable) emission pattern, any meteorology, any boundary condition;	The surrogate model is specific: it is developed just for specific meteorology and assigned boundary conditions.
The PBM is calibrated against available real data (usually representing a single emission pattern or at most the effect of a given set of control measures);	The surrogate model is calibrated on the results of the PBM when assuming a wide set of different control measures.

The surrogate model can be constructed according to different paradigms. It can be, at least in part, “mechanistic”, in which case it can be calibrated on real data and its structure can be interpreted in physical terms. Or it can be a data-based (black-box) model that cannot be calibrated on real data but processing CTM simulation data.

Annex 2 - Questionnaire

Below we have gathered the questions from the questionnaire according tro the 5 topics that they address:

Integrated Assessment Modelling (IAM) tools and methodology.
1. Which is the modelling purpose?
   - Air quality assessment
   - Mitigation and planning
   - Source apportionment
2. Which is the Integrated Assessment methodology used?
   - Cost assessment
   - Cost-benefit
   - Cost-effectiveness
   - Multi-objective approach
   - Other
3. What type of Source-Receptor relationship was used?
   - Not applicable
   - Relationship type
   - Models
   - Matrixes
   - Other

3.1. If a SR relationship was used provide the following features:

3.1.1. Input
   - Emission
   - Meteo
   - Other

3.1.2. Output

3.1.2.1. Combined use of measurement

3.1.2.2. AQI

3.1.3. Temporal resolution/Aggregation
   - Annual
   - Seasonal
   - Other

3.1.4 Spatial Resolution/Aggregation
   - grid to grid
   - grid to area
   - area to area
   - area to grid

3.2 Experiment setup

3.2.1 Design of Experiment Methodology
   - OaT
   - Factor analysis
   - Statistical based
   - Other

3.2.2 How many AQ modelling simulations were used?

3.2.3 How many meteorological reference years were used in the AQ modelling simulation?

10.Which IA indicators were used?
- Compliance achievement
- Population exposure to ….. please, specify
- Ecosystems exposure to .... please, specify
- Internal costs
- GHGs indexes .... please, specify
- External costs .... please, specify
- Other .... please, specify

Air quality modelling tools.
4. How many AQ models are you using? (up to 3) For each of these, the data base then contains information on:
5.AQ Modelling tool:
5.1 model name
5.2 Whether the model is included in the EEA Model Documentation System.
5.3 model classification
- Eulerian chemical transport model
- Lagrangian chemical model
- Lagrangian particle model
- obstacle resolving fluid dynamical model
- Gaussian plume
- Gaussian puff
- hybrid methods
- street canyon models
- semi-empirical models
- other

5.4 main features included in the model
- transport
- chemistry
- turbulence
- deposition
- specific parameterizations (e.g. urban/street increments)

Resolution and downscaling.
For each of the models used, the data base contains information on:
5.5 range of scales
- regional (5 to 50 km)
- urban (1 to 5 km)
- local (up to 1 km)
- street level (e.g. street canyon)

6. Modelling setup
6.1 Spatial resolution (if applicable)
6.2 Temporal resolution of the output
6.3 Are you using special methodologies to downscale results to very local scale (i.e. street level)?

Emissions and other model inputs.
For each of the models used the data base contains information on the model input:
Emissions
7.1 Emission inventory
- EU (EMEP)
- National emission official inventory
- Regional (or local) official inventory
- Project specific
- Other (please, specificy)

7.2 Emission inventory approach
- Top-down
- Bottom-up
- Combined
- Other (please specify)

7.3 Emission disaggregation categories (based on EMEP/EEA categories)
- main groups (e.g combustion in energy and transformation industry)
- sub-groups (e.g. public power)
- sub-activity (e.g. Combustion plants > = 300 MW (boilers))
- fuels
- others (please, specify)

Meteorology
7.4 Type of meteorological driver
- Meteorological model
- Diagnostic
- Prognostic
- Other

Meteorological measurements (data source)
7.5 Output time resolution
7.6 Spatial resolution
7.7 Initial and boundary conditions
- From a larger scale model
- From measured data
- Not applicable

Measurements and modelling.
8. If model results are combined with measurements, what are the measurements used for?
- for model validation/evaluation
- for boundary conditions
- for post-processing
- for data assimilation

9. What measurement methods are used?
- Continuous data from air quality monitoring stations
- Data from field campaigns
- Indicative (examples)
- others (please, specify)

11. **Open questions**
11.1. What have you identified as main weakness in your current approach (e.g. lack of data for validation, parameterisation of certain processes, emission factors)?
11.2. Were you able to assess the impact of abatement measures and estimate their cost-effectiveness?

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