Appraisal project

Air Pollution Policies
foR Assessment
of Integrated Strategies
At regional and Local scales

Grant Agreement number 303895

WP2: Review and gaps identification in air quality and health assessment methodologies at regional and local scale

University of Aveiro

D2.7 Summary review of air quality and health assessment methods

---

Reference: APPRAISAL / UAVR / WP2 / D2.7

Category: Coordination

Author(s): Ana Isabel Miranda, Hélder Relvas (UAVR)

Catherine Bouland (ULB)

Claudio Belis (JRC)

John Douros, Lia Fragkou (AUTH)

Les White (LWA)

Marialuisa Volta (UNIBS)

Peter Viaene (VITO)

Reviewer(s): Philippe Thunis (JRC)

Alain Clapier (University of Strasbourg)

Date: 01/07/2013

Status: Version 0.4

Availability: Public

SEVENTH FRAMEWORK PROGRAMME

Appraisal project

FP7-ENV CA 303895

www.appraisal-fp7.eu

Summary

This deliverable summarizes the outcomes of the overall APPRAISAL review of the methodologies, from simple to more comprehensive ones, used in different countries to address and assess the impact of local and regional air quality plans and their health implications. As part of the review particular attention was given to identify which relevant research activities on air pollution and its health implications, especially European Union (EU) funded, have been utilized. Regional and local scale integrated assessment methodologies were globaly addressed, but also considering the main components of an Integrated Assessment System (IAS), such as emission measures to reduce air pollution levels and the synergies between scales, modelling tools, health assessment approaches, source apportionment, and uncertainty.

Version History

Version	Status	Date	Author(s)
0.1	First Draft	11/05/2013	Ana Isabel Miranda, Hélder Relvas, UAVR
			Catherine Bouland, ULB
			Claudio Belis, JRC
			John Douros, Lia Fragkou, AUTH
			Les White, LWA
			Peter Viaene, VITO
0.2	Second draft	18/06/2013	Ana Isabel Miranda, UAVR
			Marialuisa Volta, UNIBS
0.3	Third Draft	01/07/2013	Philippe Thunis, JRC
			Alain Clapier, University of Strasbourg
0.4	Final version	14/08/2013	Ana Isabel Miranda, UAVR
			Marialuisa Volta, UNIBS

Summary of Changes

Version	Section(s)	Synopsis of Change
0.1	All	Initial version based on individual deliverables
0.2	All	Language and editing review; improvement of the document with some highlighs
0.3	All	Reviewers comments
0.4	All	Changes taking into account reviewers comments

Contents

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 for zones where the air quality does not comply with the AQD limit values and to assess possible emission reduction measures to improve concentration levels. These emissions reductions then need to be distributed in an optimal and 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) must also be considered when designing and assessing local and regional air quality plans (Syri et al., 2002; Coll et al., 2009). In order to cope with these various elements EU Member States have in the last decade developed and applied a wide range of different modeling methods to assess the effects of local and regional emission abatement policy options on air quality and human health (e.g. Cuvelier et al., 2007; Thunis et al., 2007; De Rider et al., 2008; Carnevale et al., 2011; Lefebvre et al., 2011; Borrego et al., 2012; Mediavilla-Sahagun and ApSimon, 2013).

Notwithstanding the air quality improvements within European Member States (EMS) in the last years we are still facing a continued wide-spread of exceedances, particularly regarding particulate matter (PM), nitrogen oxides (NOx) and ozone (O_3). For instance, in 2010, 21% of the EU urban population lives in areas where the 24-hour limit value for particulate matter (PM10) was exceeded (EEA, 2012).

Member States have in the last decade developed and applied a wide range of different modeling methods to assess the effects of local and regional emission abatement policy options on air quality and human health.

The European Commission is currently reviewing the air quality legislation aiming to update health and environmental standards, to establish new actions to reduce emissions for meeting interim objectives and to take into consideration costs and benefits of these actions (http://ec.europa.eu/environment/air/review_air_policy.htm). Diagnosing the methods that are available and applied in practice to carry out a quantitative integrated assessment of the effects of emission abatement policy options on the reduction of atmospheric pollutants and on human health is an essential part of this review process.

The APPRAISAL Project addresses this need to consolidate and assess air pollution and health integrated assessment research and current practices in order to support the coming revision of EU air quality policy. One of its main purposes 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), used in different countries to evaluate the impact of local and regional air quality plans and their health implications. Identifying which relevant research activities on air pollution and its health implications, especially EU funded, have been utilized is also part of APPRAISAL's main objectives.

To this end in work package 2 activities were established aiming to address this reviewing objective, more in particular focusing on:

- monitoring data and complementary methodologies to identify sources, e.g. source apportionment, in a general integrated assessment frame;

- emission abatement policies and measures planned at regional and local scales and their synergies/trade-offs with the measures implemented at the national scales;
- modelling methodologies in place across member states to assess the effectiveness of emission reduction measures at all scales; integrated assessment models to select effective air quality policies;
- methodologies to assess the effects of local and regional emission abatement measures on human health;
- techniques used to assess the robustness and uncertainties of the assessment and of the selected policies.

Limitations of the currently available assessment methods are identified, as well as key areas to be addressed by research and innovation.

This diagnosing process started by defining a common and structured online database (http://test.terraria.com/appraisal/; deliverable D2.1) in which strengths and weaknesses of the different methodologies were classified and organised around the five previously identified main areas.

Diagnosing the methods that are available and applied in practice to carry out a quantitative integrated assessment of the effects of emission abatement policy options on the reduction of atmospheric pollutants and on human health is a main objective of APPRAISAL.

Thereafter this structured database was open to APPRAISAL partners and stakeholders to collect and classify methodologies and systems from member states current practices and from research funded projects. The questionnaires were specifically addressed to national contact points in EU member states and stakeholders involved in the development of air quality plans, but also to model users applying models in the frame of research projects.This database which currently contains 63 contributions from 12 member states, concerning air quality plans and research projects, was used as a key stone for the review work that resulted in the production of 5 deliverables: (i) synergies among national, regional and local approaches, including emission abatement policies (deliverable D2.2); (ii) air quality assessment, including modelling and measurements (deliverable D2.3); (iii) health impact assessment approaches (deliverable D2.4); (iv) source apportionment (deliverable D2.5); and (v) uncertainty and robustness, including Quality Assurance / Quality Control (QA/QC) (deliverable D2.6). The analysis differentiated between the answers that were given for “air quality plans” (AQP) and those that related to “research projects” (RP). The rationale for this is that the AQP will be representative of current practice while the RP might have a broader scope since they are not necessarily aimed at drafting an air quality plan and thus may go beyond what is state of practice. Moreover, APPRAISAL reviewing relied on the expertise and knowledge of its partners and stakeholders joining all major activities on air quality and health assessment in the EU.

The final purpose of this summary review document is to contribute to improved knowledge on integrated assessment for regional air quality plans on the regional and local scale and to improve use of scientific knowledge by policy makers and regulatory bodies in member states. In line with this we first present **the state of the art and current practices**, then **limitations of the current methodologies** and **key areas for further research** are identified, and finally some **recommendations** are given with respect to the Air Quality Directive.

2. State-of-the-art and current practices

In the scope of air pollution mitigation strategies integrated assessment methodologies (IAM) have received increasing attention both in the scientific literature as well as in the european air quality directives during the last decade (e.g. Vinuesa et al., 2003; Carlson et al., 2004; Moussiopoulos et al., 2005; Oxley and ApSimon, 2007; Aman et al., 2011; Giannouli et al., 2011; Carnevale et al., 2012). The purpose of this section is to summarise the current state-of-the-art and the current practices by the member states in relation to IAM.

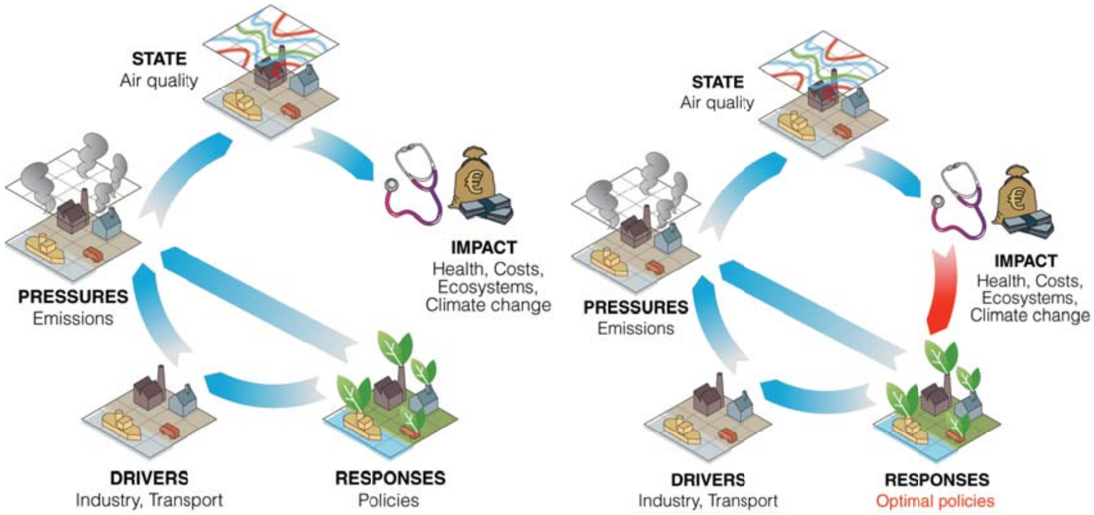
In the scope of air pollution mitigation strategies integrated assessment methodologies have received increasing attention both in the scientific literature as well as in the european air quality directives during the last decade.

2.1 Integrated assessment modelling

IAM can be considered as an approach used to decide how to reduce emissions to improve air quality, reduce exposure and protect human health. In literature different methodologies are described to evaluate alternative emission reductions:

- scenario analysis (Vinuesa et al., 2003; Vautard et al., 2007; Thunis et al., 2007) that is performed by evaluating the effect of an emission reduction scenario on air quality, using deterministic modelling simulations;
- optimization approach:
    - cost-benefit analysis (Moussiopoulos et al., 2005; Vlachokostas et al., 2009) 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 (Mediavilla-Sahagun and ApSimon, 2003; Carlson 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;
    - 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, but stressing conflicts among them.

The causal DPSIR (Driving Forces-Pressures-Sate-Impacts-Responses) framework helps comprehensively understanding these different methodologies. Figure 1 illustrates how this scheme can be applied to integrated assessment in the scope of air pollution mitigation strategies. A full description of the framework is provided in the APPRAISAL's deliverable D3.1 - First version of IAS design.



(a) Scenario analysis (b) Optimization approach

Figure 1: IAM approaches following the DPSIR scheme: (a) scenario analysis; (b) optimization approach.

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., 2011). The GAINS model considers the co-benefits of simultaneous reduction of air pollution and greenhouse gas emissions. It has been widely used in international negotiations (as i.e. in the 2012 revision of the Gothenburg Protocol) and is currently applied to support the 2013 air policy review. Some IAS at national level have been developed, starting from the EU GAINS level methodology. Two well-known implementations are RAINS/GAINS-Italy (D'Elia et al., 2009) and RAINS/GAINS-Netherlands (Jaarsveld, 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, for Germany and Europe (Builtjes et 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.

Notwithstanding some already developed and applied local/urban scale integrated assessment optimization approaches, the current practice within air quality plans develod by member states is mainly based on simpler approaches such as scenario analysis.

At the urban/local scale a few integrated assessment models have been developed and applied (e.g. Mediavilla-Sahagun and ApSimon, 2003; Vlachokostas et al., 2009; Zachary et al., 2011; Carnevale et al., 2012). 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, while accounting for characteristics of the area under consideration. RIAT solves a multi-objective optimization, in which an air quality index is minimized constrained by a specific emission reduction implementation budget. An important feature of RIAT is the use of a nonlinear air quality model to link emissions and concentrations over the study domain. The Luxembourg Energy Air Quality model (LEAQ) (Zachary et al., 2011) integrated assessment tool focuses on projected energy policy and related air quality 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 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 volumes and composition.

In spite of some already developed and applied local/urban scale Integrated Assessment (IA) models, which include cost-benefit, cost-effectiveness and multi-objective analyses, the current practice within air quality plans developed by member states is mainly based on simpler approaches, such as “scenario analyses”.

A very important aspect of using IAM to support policy making concerns uncertainty. The “UNECE workshop on uncertainty treatment in integrated assessment modelling” (UNECE, 2002) concluded that policy makers are mainly interested in robust strategies. Robustness implies that optimal policies do not significantly change due to changes in the uncertain model elements. Robust strategies should avoid regret investments (no-regret approach) and/or the risk of serious damage (precautionary approach) (Amann et al., 2011). This issue is also linked to the need of defining a set of indexes and a methodology to measure the sensitivity of the decision problem solutions.

2.2. Integrated Assessment components

Taking into account member states’ current practices different components of an IA system were identified, namely: (i) source apportionment; (ii) emission reduction measures at different scales; (iii) air quality modelling approaches; (iv) health effects of air pollution; and (v) uncertainty.

In the **scenario analysis** approach, source-apportionment can be used to identify the main emission sources that contribute to air pollution concentrations. Emission reduction measures are selected and/or established taking into consideration synergies at different scales. The effect of these measures on the air quality improvement is quantified using air quality modeling systems and afterwards translated to health effects.

In the **optimization approach**, the emission reduction measures are selected by an optimization algorithm assessing their impact on air quality, health exposure, implementation costs. Such optimization algorithms requires thousands of air quality assessments; in these cases, AQ systems cannot directly be used because of the computing time demand, so they provide tens to hundreds simulations processed to identify ‘simple’ emissions-AQ links (source-receptor relationships).

Uncertainty is a common and transversal topic which is detailed for each model component individually. It is worth noting that there has been a long standing ambiguity as to the exact meaning of the term “uncertainty”. In the literature, the term has been associated both with the evaluation process as well as to represent the stochastic character of natural variables inside models. The two are of course closely linked, but the methods used for the quantification and study of each of the two can differ substantially. It appears from the results of the APPRAISAL database that uncertainty was mainly considered as an evaluation process in the air quality modelling part of the IAM applications.

2.2.1 Source Apportionment

Source Apportionment (SA) is the practice of deriving information about pollution sources and the amount they contribute to ambient air pollution levels. Different approaches are used to determine and quantify the impacts of air pollution sources on air quality, namely: exploratory methods; emission inventories; inverse modeling; artificial neural networks; source oriented models (such as lagrangean, gaussian, and eulerian models); and receptor models.

Source apportionment (SA) is the practice of deriving information about pollution sources and the amount they contribute to ambient air pollution levels.

The study by Viana et al. (2008) focused on receptor model source apportionment studies in Europe from 1987 to 2007. PM10 was the preferred target metric (46%) followed by PM2.5 (33%). The majority of the studies were carried out in urban background locations. Overall, a generally good spatial coverage of SA studies over Europe was seen and four main source categories were identified: traffic source; mineral/crustal matter source; sea salt, sea-spray and marine source; regional scale pollution and long-range transboundary anthropogenic pollution sources.

A dramatic increase in the number of scientific publication on SA receptor approaches during the last decade and an increasing number of ready-to-use tools was identified.

Karagulian and Belis (2012) updated this review on receptor models for PM source apportionment in Europe between 2001 and 2010. A dramatic increase in the number of scientific publications on this topic during the last decade and an increasing number of ready-to-use tools was identified. The highest rate increase in the number of studies coincides with the adoption of the limit value for PM10 (1999/30/EC) and the target value for PM2.5. About 60% of the studies were carried out in urban background sites, 16% in source oriented sites, and 15% in rural sites.

The prime reasons of MS for using SA within the framework of integrated assessment studies are associated to obligations linked to the AQD (2008/50, Article 22, Annex XV - 2011/850 (Article 13, Annex II): design air quality plans or action plans, identify the causes of exceedances, and identify the contribution from other countries (transboundary pollution). Other motivations for SA studies are the evaluation of geographic origin within a country (not transboundary), application for postponement of attainment and assessing the effectiveness

The prime reason for member states for using SA within the framework of integrated assessment studies are associated to obligations linked to the Air Quality Directive.

of measures. The great majority of the studies focus on the city level while local (lower than city) and regional scales are also represented.

Results from two surveys on the “Contribution of natural sources and source apportionment” carried out within the activities of the Forum for Air Quality Modelling in Europe (FAIRMODE) confirm the type and popularity of the different modelling tools that are used in Europe for source apportionment (Fragkou et al., 2012). The first survey was launched when the European Commission announced the decision on the applications for the time extension presented by 17 MS, for 289 air quality zones. It is worth mentioning that the majority of the countries (71%) applied a combination of receptor and source-oriented modelling approaches. The high share of eulerian and lagrangian models can be explained by the interest of many MS to support their claim that most of the pollution episodes originate outside their boundaries and are thus due to long range transport. On the other hand, receptor models were used to identify sources at the urban or regional level. Objective estimation and inverse models are used marginally for the identification of sources.

Understanding the factors that contribute to the **uncertainty** in SA studies is quite complex, since the actual contribution of pollution sources to the level of pollutants observed using measurement instruments is unknown. As in every model, the uncertainty in source apportionment models’ outputs depends largely on the quality of the input data.

While only one third of the receptor studies published before 2010 reported source contribution uncertainty, this value has increased to two thirds for the studies published since 2010 (Belis et al., 2013). Recently, a methodology to evaluate intercomparison results on the basis of international standards for proficiency testing exercises has been used (Karagulian and Belis, 2012). At present, almost 400 source contributions estimated by 38 participants have been evaluated in two european exercises (Karagulian et al., 2012). The results indicate a good quantitative agreement between the reported source contribution estimates. More than 80% of the solutions meet the quality criteria corresponding to a 50% standard uncertainty.

In most EU source-oriented SA studies reported in the literature the evaluation of results is indirectly accounted for and that efforts to systematically evaluate the performance of alternative methodologies and estimate their intrinsic uncertainties have been scarce (Viana et al., 2008; Favez et al., 2010). However, in the scope of FAIRMODE a high percentage (88%) of reported SA studies have evaluated their results. The most frequently used SA evaluation method was by comparing model results to data obtained from dedicated measurement campaigns (59% of reported studies corresponding to 55% of EU countries).

In the overall IAM framework, source apportionment methodologies can bring added values at different stages of the process:

− During the set-up phase of an IAM framework the identification of the key emission sources in the area of interest would allow a better delimitation of the problem and therefore to allocate resources to study in depth the identified more relevant sectors of activity (e.g. no need to invest resources to get details on emission sectors which are of minor importance)

− One of the key aspects determining the overall robustness of the IAM system is the evaluation of the air quality modelling system used to derive the source-receptor relationships. Although the information retrieved from source apportionment studies is not always fully compatible with the output of AQ models, the comparison of the two approaches will certainly result in a better quality and understanding of the whole system.

− SA could also be used to determine the amount of pollution originating from outside the considered domain where the IAM system is applied. One of the ways to retrieve this information is, of course, with the use of larger scale models but SA methodologies (especially those involving lagrangian models) could help assessing this component as well.

− There could be a synergistic use of SA and IAM techniques like scenario analysis or optimization based approaches, such as cost-benefit, cost-effectiveness, multi-objective approaches. To that end, SA could drive the choice of the emission patterns to be tested through scenario analysis as to limit the number of simulations to be performed with a CTM. As an alternative, it could limit the degrees of freedom of cost-effectiveness analysis, constraining the optimal solution to consider only a subset of the possible emission reductions to those previously identified by applying SA.

2.2.2 Emission reduction measures at different scales

Even though emissions do not represent the actual contribution of sources to atmospheric pollution, many local governments use the emission inventory directly as source identification tool for the design of abatement measures (Ulrike Döring, Pilot Project, personal communication).

For setting up emission inventories at the continental and national scales the IPCC (2006) and EEA (2009) guidelines are currently the standard, accepted methodologies. Taking into consideration that emissions are a source of significant uncertainty policy-makers have pursued continuous improvement of the reliability of national emission inventory data (e.g. DEFRA, 2010). 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 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).

Nowadays the current practice regarding setting up an emission inventory is a combined approach using both a bottom-up and top-down methodology.

Urban, local and street level studies represent more than 80% of studies using a bottom-up approach.

Nowadays the current practice regarding the approach used in setting up an inventory is a combined approach using both a bottom-up and top down methodology. This is not surprising as official national and regional inventories are also usually constructed using this complementary approach. Urban, local and street level studies represent more than 80% of these studies using a bottom-up approach.

Comparing the scale of the emission inventory with the scale of the study 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.

The AQ community is aware of several potential problems associated to missing or accounting in an incomplete way the synergies among abatement measures at different scales. One main issue is the inconsistent formulation of emission inventories in terms of spatial scales. The need for coordination and synergy in order to produce effective plans is clearly recognised.

The main way policies at different scales are accounted for depends on whether the focus is on air quality planning or air quality modelling. If it is the former, the emphasis is on ensuring that improvements expected from national policies are accounted for in smaller scale plans. If it is the latter then the impact of larger scale emissions as background concentrations is considered.

The air quality community is aware of several potential problems associated to missing or accounting in an incomplete way the synergies among abatement measures at different scales, but coordinated policy measures are not yet explicitly considered.

Certain control measures only apply to a small fraction of the emissions that belong to a certain SNAP sector. Traffic related emissions (SNAP 7) were the focus of most AQP with less prominent roles for non-industrial combustion (SNAP2) and combustion of manufacturing industry (SNAP 3). This is of course related to the pollutants targeted: 80% of the revised plans target nitrogen oxides for which traffic and combustion in general is the main source. To consider such measures adequately in the AQP, emissions need to be further disaggregated and assigned to subsectors, activities or fuel type to which the measures apply. More than 60% of the AQP consider a further subdivision of the SNAP level1 macro-sectors into sectors and activities and 55% consider more than one level of detail.

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. 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 very few studies are dealing with this topic (van Ardenne, 2002; van Gijlswijk et al., 2004; Werner et al., 2005; Werner, 2009).

2.2.3 Air quality modelling and Integrated Assessment approaches

Air quality modeling is needed to assess a set of emission reduction measures (scenario analysis) or to establish SR relationships as part of the Integrated Assessment Modeling (optimization approach).

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

Chemical transport models have become widely used tools for assessing the effectiveness of control strategies adopted by regulatory agencies in the scope of scenario analysis approach.

Air quality modelling is needed to establish relationships as part of the integrated assessment system when optimization approaches are used.

strategies adopted by regulatory agencies.

A comprehensive list of air quality models used in Europe can be found in the EEA (2011) Model Documentation System (MDS), 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. 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.

According to the results from the APPRAISAL database approximately 70 % of models used to draw up air quality plans are included in the EEA Model Documentation System. Considering the models' classification eulerian chemical transport models are clearly the most used in air quality plans (40%) followed by gaussian plume models (22%).

Apparently people nowadays in charge of air quality studies feel that regional scale air quality models are the most appropriate tool. 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. 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.

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.

Regional scale models are nowadays considered as the most appropriate air quality study tools.

The models used at urban scale are essentially the same models as those used at regional scale.

After regional scale models, the second largest class of models used is represented by street scale models.

After regional scale models, the second largest class of models used is represented by street scale models. These models parameterize the circulation in the canyon or explicitly calculate it. 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.

In order to rely on model results for air quality decision making, both model performance evaluation as well as uncertainty estimation are of imperative importance. Dennis et al. (2010) propose four types of model performance evaluation:

- operational evaluation involves assessment of model results compared with monitored data.
- diagnostic evaluation is a process-oriented analysis to determine whether the individual physical and chemical processes are correctly represented in the model.
- dynamic model evaluation is the analysis of model responses to changes in model input data.
- probabilistic model evaluation is performed on the basis of methods such as model inter-comparison and ensemble modelling, and attempts to capture statistical properties, including uncertainty or level of confidence in the model results, for regulatory model applications.

In terms of the evaluation methodology used for AQP based on scenario analysis, operational and diagnostic methods are applied more often than the other methods, while expert judgement is also reported in a significant number of studies. Evaluation methods of higher complexity, such as dynamic and probabilistic approaches, were only applied in very few cases. There are several AQP relying only on model performance analysis from previous studies.

Air quality plans often include operational or diagnostic model evaluation; expert judgment is also reported, and there are several plans relying on model performance analysis from previous studies.

The development of specific software tools for model evaluation is mainly related to operational model evaluation, as the tools provide a platform for statistical analysis of model results compared to measurements. Examples of validation tools include the BOOT model evaluation software package (e.g. Chang and Hanna, 2004) and the Atmospheric Model Evaluation Tool (AMET) for evaluating meteorological and air quality models (Appel et al., 2011). The DELTA Tool which has been developed within the frame of FAIRMODE activities (Thunis et al., 2012) is a model evaluation software which delivers summary statistics (i.e. BIAS, RMSE, correlation coefficient) as well as scatter-plots, time series plots, Taylor, Target and other diagrams providing an overview of the quality of model results against available

No reference technique is proposed so far to check the quality of the models used to quantify the impact of emission reduction scenarios in air quality plans.

observations. A benchmarking service is also implemented in the DELTA tool, which automatically produces standardised summary reports containing performance indicators related to a given model application according to AQD requirements.

The quality of the model results for planning applications (typically to investigate the impact of an emission reduction scenario) is not explicitly assessed, but relies on evaluated model performance for assessment purposes. This is probably related to the fact that as planning applications refer to future time, no reference observations exist to compare model results with. Probabilistic model evaluation could be particularly helpful for predicting the accuracy of model results for future emission changes, and it is therefore considered essential for future planning purposes (Hogrefe and Rao, 2001), however it is relatively time-consuming and often require qualified personnel and infrastructure resources, which are usually only available within a research project. It is interesting to note, that no reference technique is proposed so far to check the quality of the models used to quantify the impact of emission reduction scenarios in AQPs.

Apart from model evaluation, in about 1/3 of the APPRAISAL compiled studies measurement data is also used for other purposes such as model calibration, the boundary conditions of local or street canyon models, post processing and data assimilation. 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.

2.2.4 Health effects of air pollution

Health effects of air pollution are part of IA, which uses one or more indicators to express the change in population health status due to exposure to air pollution. When different health effects are considered, it is important to distinguish between acute effects related with short-term exposures and chronic effects resulting from long-term exposure. The impact of long-term exposure effects is often larger than those associated to short-term exposure (Beverland et al., 2012). Short-term exposure, with the capability to cause acute health effects, has traditionally attracted most concern. However, recently it has been recognised that chronic effects resulting from cumulative (including lifelong) exposures are often a more important public health problem (Briggs et al., 2009).

Health effects of air pollution are part of integrated assessment, which uses one or more indicators to express the change in population health status due to exposure to air pollution.

The most common used indicator is premature mortality. Other common indicators are morbidity, life-expectancy, and recently more and more popular disability-adjusted life years.

The selection of the health indicator depends on the stressor studied, availability of data, computer resources, skills, and purpose of the study. For example, cost-benefit studies usually prefer to list all mortality and morbidity outcomes to compare all health benefits with all the costs of mitigation actions. Some other IA studies involving multiple stressors might require indicators that take into account age, or both mortality and morbidity effects.

The most commonly used indicator is premature mortality, with different variations. Other common indicators considered are morbidity, life-expectancy, and recently more and more popular disability-adjusted life-years (DALY). The mortality indicator has been criticized because the measure does not provide any information on how premature the actual death is (e.g. Brunekreef and Hoek, 2000; Rabl, 2003) i.e. the premature death does not distinguish between a case where death is advanced by one day from the situation of one year, or one decade. This might give misleading information in cases where the stressors impact different age groups. For example, stereotypical traffic accident fatality occurs for 20+ year old male while air pollution related lung cancer deaths occurs at much later age. Other indicators, such as years of life lost (YOLL) has been introduced because of the most basic criticism that deaths cannot be directly attributed to any stressor. Therefore mortality is mainly a conventional measure of health and it is widely used in IA studies because it can easily be understood and the availability of data.

Exposure-response functions are often derived based on epidemiological studies e.g. effect of air pollution on mortality rates. In general, epidemiological studies that have used finer spatial resolution to relate people to air pollution levels tend to report higher mortality/morbidity impacts (Tainio, 2009). Therefore a recommendation is to use the most detailed exposure estimate available for epidemiological studies assessing the health effects of air pollution, e.g. for pollutants with high spatial variability this can be based on personal activity-based modelling or personal dosimetry.

A distinction has to be made among the various pollutants for which the health impact relationship is known. Recently, the focus has been on air particulate matter, but other pollutants have also been studied. Pope and Dockery (2006) have emphasised the importance of particulate matter with aerodynamic diameter < 2.5 μm (PM2.5) from a health perspective. They indicate that this smaller fraction is of immense importance and appears to be more significant than PM10 (Pope and Dockery, 2006). Also the World Health Organization (WHO) has mentioned that there is increasing evidence that the PM2.5 fraction contains the principal harmful particles (WHO, 2003). However, although fine particles are often blamed, coarse particles from e.g. tire and brake wear could be implicated in health effects as well (Riediker et al., 2008; Gasser et al., 2009).

In the CAFE programme an impact function (exposure-response function), estimating years of life lost (YOLL) by chronic exposure to PM2.5 for the adult population (+30 years), was presented based on exposure-mortality relationships and inclusive life table analysis (Hurley et al., 2005). The same approach has also been tested and applied at regional scale (over Northern Italy) (Carnevale et al., 2012). In this study, considering all age categories 651 YOLL are associated per 10 μg/m^3 increase of PM2.5 per 100,000 people considering all ages.

For ozone current HIAs only take into account effects of short-term exposure to ozone peaks (mortality, MRAD or minor restricted activity days, hospitalisations for respiratory symptoms, use of bronchodilators, cough days, days with problems of the lower respiratory tract). More evidence is published on ozone effects after long-term exposure to ozone (e.g. for mortality see Jerrett et al., 2009). This may be taken up in future HIAs as sensitivity analysis.

The choice of the pollutant, cocktail of pollutants or an indicator as proxy for an exposure situation in HIA is also restricted by the available scientific knowledge on the pollutant or cocktail of pollutants, on scientific knowledge on health effects and the way to measure those effects (causality) (REVIHAAP & HRAPIE, HEI 2013). For instance, currently there is new evidence supporting HIA for NO_2 (http://www.healtheffects.org/Workshops/Brussels2013/Presentations/Krzyzanowski.pdf).

It is not a current practice to integrate health effects issues in air quality plans.

It is not current practice to integrate health effects issues in air quality plans. The air pollutants considered most frequently in AQP when health aspects are accounted for are particles (PM10 and PM2.5), nitrogen oxides (NOx) and ozone (O_3). They are mostly based on identified and monitored pollutants, their sources, their behaviour in the atmosphere and their effects on the environment and on human health in the context of a geographic, institutional and economic situation. Notwithstanding the fact that these AQP are mainly using air quality interpolated monitored data to assess health effects of air pollution, the use of air quality modeled data is also acknowledged. The most common indicator is premature mortality, with different variations.

Half of the studies carried out were executed in the framework of economic assessments. The methodology used aimed at determining how much money could be saved or lost if a preventive approach was taken.

PM10, PM2.5, NOx and O_3 are the most frequently considered pollutants in air quality plans when health aspects are accounted for.

Uncertainy of health impact assessment is a very important topic. The main sources of uncertainty can be summarised as follows:

- uncertainties related to the results of the epidemiological studies or to their generalization;
- uncertainties in estimating the impact for each health outcome;
- uncertainties in exposure assessment;
- uncertainties related to the concentration-response functions, estimated by epidemiological models;
- uncertainties concerning the temporal scale of effects, i.e. the latency times from exposure to adverse event;
- uncertainties related to the exposure reference value.

3. Limitations of the current assessment and planning tools and key areas for future research and innovations

This section identifies limitations of the currently available assessment methods taking into consideration the previous diagnosis, and proposes key areas to be addressed by research and innovation. It is organised in several sub-sections, starting with the IAS individual components and finishing with the IAS itself.

3.1 Source apportionment methodologies

Classical methods to do source apportionment, such as **receptor and source-oriented modelling approaches are available and becoming more widely used by member states**. Nevertheless, it must be clear that even the most advanced tools have strengths and limitations. For instance **receptor models are appropriate for urban areas and source-oriented sites**, and can be used to identify main source categories even when there is poor information about source chemistry and location. **However**, these receptor models **require time series of pollution measurements and chemical characterization and are not adequate for reactive species**. In that case **source-oriented approaches**, such as eulerian models, **that provide estimates of reactive species concentrations for every cell in the grid with hourly time resolution are suitable to estimate the sources of secondary pollutants**. The complexity of these types of models makes it difficult to estimate the uncertainty of the output, which depends on the quality and resolution of the emission inventories. Therefore, the most robust approach to deal with source identification is the use of different models with the same data or with different data for the same area to simultaneously validate the results and assess the quality of the output quantitatively.

An example are hybrid trajectory based receptor models that combine the analysis of wind direction or backward trajectories with receptor models information to calculate the probability of a trajectory crossing over a cell and reaching the receptor site when the pollutant concentrations or source contributions are above a selected threshold (e.g. Ashbaugh et al., 1985). Even if this kind of models has been available for a long while, they have found little application in Europe. Moreover, hybrid receptor models, which take advantage of information on pollutant physical and chemical properties and on the processes that influence them, are currently available and ready to use as tools.

All these tools require experienced users and tested, operational protocols including validation steps to achieve acceptable performances. This could be the reason why this type of SA methods and tools are not yet applied regularly by MS to identify sources. There is also the need of long term speciated PM datasets and characterization of source fingerprints to further improve source identification studies. In addition, harmonization of the different approaches would facilitate the interpretation and comparability of the results and their application in the design of abatement measures.

Notwithstanding the potential contribution of classical SA methods to IAM, the optimization approaches can automatically perform source apportionment establishing the most cost-effective emission reductions and identifying the sources categories associated to these reductions. This could be seen as a generalization of the source apportionment approach without the need to measure and chemically characterise air pollutants.

3.2 Synergies among national, regional and local approaches, including abatement technologies

Until very recently, European level integrated assessment has not been designed to directly assess strategies to deliver compliance with air quality limit values. There are a number of reasons for this; here we highlight just four important ones.

(i) Limitations from modelling scale: The first is the difficulty of modelling the whole of the European region at a fine enough scale to contribute anything meaningful to the understanding the relationship between further european-wide measures and air quality compliance at a given air quality monitoring station.

(ii) Limitations of country-wide activity proxies: The second is that by its very nature, european-wide modelling is 'top down' and uses average country-wide proxies for key activities that strongly influence compliance at a given monitoring station. The specific efficacy in a given urban zone, even of measures set at the european level will only be approximated by such a top down approach. Furthermore, such approaches are not suitable for exploring the role of non-technical or zone specific measures such as low emission zones or captive fleet retrofits and fuel changes. Exploring these strategies as a route to achieving compliance requires a bottom up approach.

(iii) Limitation of Country to Grid S-R: Thirdly, current european-wide or top down approaches are limited to 'country to grid' relationships between an emission change and the corresponding change in concentration in a given grid. Clearly this limits its application to exploring national level initiatives.

(iv) Limitation of Annual Impact Focus: Fourthly, and finally, at the european scale, relationships between emission changes and air quality are limited to annual mean values whilst some of the more challenging air quality limit values are based on daily or hourly averages.

It is important to note that while such limitations impact the ability of this top down approach to directly assess compliance with air quality limit value at individual measuring stations, the use of european scale IAM to inform the targets of the current Thematic Strategy on Air Pollution indirectly contributes to further progress in reaching compliance.

This inability of European scale IAM to directly address the compliance challenge (at least until very recently) has contributed to some of the difficulties in achieving compliance with AQ limit values (e.g. PM10 and NO_2) from the implementation of Europe-wide measures in a number of member states. The formal **air quality plans designed to address the non-compliance issues have largely been based on bottom up approaches using combinations of local air quality modelling and measurements/measurement campaigns**. As we have already begun to see from the pilot questionnaire results, while essentially all responders recognise the need to appropriately account for the wider scale, not all have been able to bring the local (bottom up) and european/national scale together.

In this regard, the emergence of regional integrated sssessment tools with their ability to identify cost-optimised local strategies is already opening the door to **quantifying the cost-effective split between further european wide measures and regional/local measures**. They will inevitably need to find wider application and play an increasing role in this emerging 'discrete islands of non-compliance' EU.

This points to an increasing role for targeted technical and non-technical measures in order to achieve compliance. As already noted, such measures (low emission zones, special fuels for captive fleets, captive fleet retrofitting etc.) can only be appropriately designed using bottom up tools. **To compute emission reduction scenarios and policies, it is necessary**

to combine emission inventories and technical and non-technical databases.

Another weakness highlighted in the APPRAISAL database is the uncertainty and **lack of data** (activity, emission factor) for **quantifying anthropogenic emissions for new technologies**, in particular new energy sources and new vehicles. 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 an issue of data consistency when combining date from these different sources. In fact, regional policies range from incentives or regulations on end-of-pipe technologies to energy efficiency measures. These last options are often fundamental at a regional level to reach EU air quality standards. 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.

3.3 Air quality and integrated assessment modelling

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 on 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 limitations 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.

Moreover, there are still some processes that require a better description within the models including:

- aerosols: In general air quality models tend to underestimate PM concentrations significantly while at the same time exceedances for PM are often considered the most problematic in terms of health impact. **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 (< 1 km) where the meteorological models start to resolve turbulent eddies. 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.

Measured concentration levels contain valuable information which can be used as additional input to modelling results. In that respect, it is striking that in 40% of the APPRAISAL 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, if a linear approach is suitable for the domain. 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.**

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

In the APPRAISAL database 70% of the respondents identified emissions as the main weakness of their modelling approach. The quantification of the effectiveness of specific measures for a zone presumes that the emission inventory disaggregates the emissions both spatially and according to the level of detail required by the measures considered. This level of detail is unfortunately lacking in most inventories and is a major source of uncertainty in assessing the effect of measures. The official national and European (EMEP) level emission inventories do not cater for this level of detail and only contain emission totals for the member state as a whole. 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.

Relevant information on desirable practice for compiling such emission inventories can be found in the guidelines of the FAIRMODE's work group on 'Urban emissions and Projections' (FAIRMODE 2010) and the report on 'Integrated Urban Emission Inventories' of the Citeair2 INTERREG project (Davison et al.,2011).

3.4 Health impact assessment

Traditionally modelling tools have addressed air quality assessment issues including dispersion and chemistry but have not extended their capability by incorporating exposure or other health indicators. However, **Health Impact Assessment (HIA) should be part of integrated assessment tools** (Bickel and Friedrichet al., 2005), as it usually involves a combination of procedures, methods and tools by which a policy or suggested air quality mitigation measure can be judged as to its potential effects on the health of a population. Quantification of health effects in HIA is particularly important (Bell, 2006, Nouwen et al., 2001), **as knowing the size of an effect** (Pope et al., 2002) **helps decision makers** to distinguish between the details and the main issues that need to be addressed and facilitates decision making by clarifying the trade offs that may be entailed. Secondly, **adding up all positive and negative health effects into a net effect using appropriate modelling methods permits the use of economic instruments such as cost effectiveness analysis** (Amann et al., 2011), which further aids decision-making.

The exposure-response function (which quantifies the change in the population health due to a given exposure) is identified to be the main source of uncertainty in an integrated assessment (Tainio, 2009). The following research needs in relation with the exposure assessment were considered to be important for HIA:

- The need to further explore the "complete individual exposure to air pollution" is strongly felt. With "complete" meaning as well indoor as outdoor air pollution and a period of 24h/24h. With "individual", monitoring the air quality at the level of the person itself, using portable-and-easy to wear monitors is meant. These two factors will eventually result in a more complete view on the individual exposure to pollutants. If this could be combined with human biomonitoring, i.e. measuring the concentration of a certain pollutant or one of its by-products in the human body, this would be a real added value to our current knowledge concerning the impact of air pollution on human health.
- The distance to relevant traffic lines is known to have a crucial effect on population exposure and health effects and should be further investigated.
- The dynamic dimension of individual exposure and its integration of successive environments such as indoor and outdoor, should be further investigated in order to come to a better understanding of the relationship between microenvironments, activities and lifestyle and human exposure.
- Individual and population exposure studies are needed for a better understanding of the link between air quality levels, exposure, individual doses and health effects.
- More detailed modelling tools are needed to assess the population exposure to pollutants, not considering simple static maps of population and pollution, but dynamic ones (i.e. considering hour-by-hour where the population is

living/working, depending on age, gender, activity... and modelling air quality maps with the same level of detail, to compute the real population exposure).

Generally, projects are focused on long-term exposure that has much greater public health impact. Some acute effects are included in chronic effects, but not all short-term health impacts are included in long-term impacts, therefore, short-term impact on mortality might be underestimated.

3.5 Integrated Assessment System

Notwithstanding there are already some IAM tools available for use at the urban scale, current assessment and planning is mainly based on scenario analysis approaches through the application of air quality models, which nowadays are used quite regularly. 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. If it is true that a linearization works at european/national scale, at regional level or at low spatial resolutions it is still unclear to what extent the nonlinear dynamics in the formation and accumulation of secondary pollution can - be ignored or underestimated . Future research will need to assess **the importance 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.

It is important to note that IA can at the current stage of development in the air quality sector not be thought of as a specific procedure and, even less, as a unique tool. At regional and local level in the EU, besides the obvious physical differences, there is also a large variability in the detail of available data and an even larger disparity in the decisional power of the involved agencies. IA must thus be interpreted as an approach which flexibly links decision making, air quality dynamics, emission reduction costs and health impacts to suit the capabilities and requirements of each regional/local situation.

In fact, 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.**

Uncertainty estimates are an essential element of integrated assessment. Uncertainty, information is not intended to directly dispute the validity of the assessment estimates, but to help prioritise efforts to improve the accuracy of those assessments in the future and guide decisions on methodological choices with respect to the tools that are being used.

In order to assess the total uncertainty and evaluate the performance of an IAM system, the uncertainty related to the different modelling components of the system (meteorological modelling, air quality modelling, exposure modelling, cost-benefit modelling) has to be quantified separately. However, **it remains a scientific challenge to interconnect all the individual uncertainties of IAMs**, as the chemical and physical processes involved are not linear and, also, some uncertainties may compensate each other. Combining all uncertainties to calculate a total uncertainty would require a great number of simulations to take into account all possible combinations. **This complexity does not allow for setting straightforward quality criteria in terms of IAMs, even though IAM is considered an important policy tool.**

It is in fact worth underlining that, while for air quality models the sensitivity can be measured by referring in one way or the other to field data, for IAMs this is not possible, since an absolute “optimal” policy to which the outcome of an IAM could be compared is not known and most of the times does not even exist. **The traditional concept of model accuracy must thus be replaced by notions such as risk of a certain decision or regret of choosing one policy instead of another.**

4. Contribution to the Air Quality Directive Review

The current European Directive 2008/50/EC on ambient air quality and cleaner air for Europe (AQD) encourages the use of air quality modelling, in combination with monitoring, as a scientifically relevant tool for a range of policy applications. Models may be used to assess and predict exceedances and high-pollution areas, to identify the main polluting sources, to develop air quality plans and mitigation strategies and to perform risk assessment in the case of accidental atmospheric releases.

In general the European Directive 2008/50 and more recently the Commission Implementing Decision 2011/850 do not specify what methodology is required to devise efficient measures to improve the quality of the air. The contents of the template provided for reporting however indicate that **a scenario approach supported by source apportionment can be useful** addressing the following:

1. Source apportionment: Which are the main emission sources responsible for the pollution, distinguishing local and regional (transboundary) contributions? With which accuracy is the emission source base case known?
2. 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?
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?

With respect to **emissions**, the Directive 2008/50/EC requires an air quality plan reporting the origin of pollution (Annex XV) by providing a list of the main emission sources responsible for pollution (map) and the total quantity of emissions from these sources (tonnes/year). The Commission Implementing Decision of 12 December 2011 requires the AQP to report on the emission scenario and the total emission for both the baseline and for the projection as well as the reduction in annual emissions due to the applied measures.

In fact, the Directive acknowledges the importance "to identify and implement the most effective emission reduction measures at local, national and Community level" (article 2). This presumes that:

1. the emission inventory used for the AQP is sufficiently detailed to allow mapping measures to the specific emissions managed at the different administrative levels that have to be considered.
2. the costs of emission reduction technologies are available.
3. a suitable optimization approach to select effective policies can be implemented.

Emission inventories and projections as needed for the assessment and planning at the local scale are currently developed *ad-hoc*. It is recommendable to take an initiative **to harmonize the criteria and the procedures for developing such local emission inventories**. Further fixing and specifying these procedures might improve emission data necessarily needed for air quality modelling and in consequence will improve modelling results for this part.

Moreover, the effectiveness of any type of remediation measure strongly depends on the reliability of the pollution source identification and quantification process. Hence, the use of methodologies with minimum biases and uncertainties certainly contributes to **focusing valuable resources and time on the most contributing sources in the area of interest**.

Article 25 of the Directive deals with the problem of **transboundary 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.

On the other hand the problem of transboundary air pollution can be read as the issue to assess the impact of regional-local emissions, in other words, **to quantify the effective potential of regional-local policies in a specific domain**. Methodologies shoul be formalized and developped to fill this gap.

Integrated Assessment Modelling (IAM) should support the air quality authorities in selecting efficient mitigation strategies by providing tools for assessing and solving air quality planning problems at different spatial scales. AQ modelling is the IAM component explicitly mentioned in EU legislation. 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.

As the role of modelling in understanding the influence of physical and chemical processes on the dispersion and transformation of pollutants is increasingly being recognised, and MS are already using models in their current assessment techniques it is recommended to further promote the use of modeling tools in the scope of the nowadays AQD revision. Moreover, 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 and any such modelling based report should include a complete description of the model and inputs used as well as an evaluation to quantify the reliability of the AQ assessment.

Today many different modelling tools exist that are being used for AQ assessment and planning so 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**.

The need to **incorporate uncertainty estimation in air quality modelling is** also **recognised by policy makers** and is required by the AQD, which specifies modelling quality objectives. As the directive does not provide guidelines on how to carry out model evaluation to achieve the quality requirements imposed, the **development of relevant guidelines is necessary for modellers and authorities**. Several attempts have been made for the establishment of uncertainty assessment guidelines within a number of projects, including AIR4EU (Denby et al., 2011) and FAIRMODE. The Guidance Document that was elaborated within FAIRMODE (Denby et al., 2010) is the current reference point for model users and regulators to ensure that their air quality model meets the quality criteria required by EU legislation.

Another important issue for a proper model application when developing an AQP, 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 in 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.

For accurately assessing health effects of air pollution, detailed exposure estimates need to be available. Aggregating monitored data collected by different monitoring stations or concentrations measured at central monitoring stations or proximity measures does not seem to reflect the personal exposure. Estimating detailed personal exposure to air pollutants should be addressed more. Indeed, individual exposure studies should include parameters affecting their exposure (cultural, socioeconomic, ethnic, *etc*.). Although most health outcomes are not confined to a single pollutant, studies typically focus on the risks of single pollutants and do not consider the mixture of pollutants. **There is a clear need to develop methods for evaluating and managing the effect of the air pollution with a multi-pollutant approach.** However, it should also be remembered that particulate matter (PM) air pollution is already by itself a mixture of solid and liquid elements and not a single pollutant.

Health impact assessment shall consider the simultaneous exposure to multiple pollutants and particularly vulnerable groups of population. Usually, interaction among these different pollutants and the combined effect of these with pollutants that are naturally present in the environment are not included. Furthermore, epidemiology study carry out the potential HIA in the future are based on health outcomes measured in the past which is combined with a given exposure to a given pollutant, whereas more events may occur at any time, namely, due to changing air quality and to the characteristic of the population for the study period.

5. Final comments

In this deliverable we have summarized the results of the review activities of the APPRAISAL project on the following themes:

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 uncertainty
5. robustness, including Quality Assurance / Quality Control (QA/QC).

In the first chapter 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 elaborated methods using optimization methods are still more in the research realm. For air quality assessment currently no standard modelling tool is used but rather many different models are being applied (most of them are included in the EEA model database) . Overall, the resolution of the emission inventory and other inputs are adapted to the studied geographical zone. This indicates that many people are aware of scale issues at least to a certain extent when they assess air quality and draft air quality plans.

The second part focuses on the current practice limitations and identifies areas where further research is needed for the different subtopics. 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 within 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 which are however 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 while standards such as the EMEP emission inventory are available at the european level 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 can best be combined with observed values in scenario calculations.

In the overall IAM framework, source apportionment methodologies can bring added values. In fact, in recent years the number of studies on source apportionment in Europe has steadily increased. This is closely related to the continuous development and improvement of tools with respect to functionality and performance. Nevertheless, the lack of an appropriate european network of urban monitoring sites with detailed chemical and physical characterization of aerosols is becoming a limiting factor for a further growth and consolidation of SA techniques for these important pollutants. This is true for both receptor models and eulerian models. From the methodological point of view, a combination of both receptor models and eulerian models possibly complemented with other techniques (mainly lagrangian models) appear as the most dynamic area in the further development of source apportionment tools. Another innovative way of doing SA is to directly profit from the IAM system, because it automatically delivers the most cost-effective emission reduction measures by source category.

The IAM optimization approach fully responds to the AQ Directives. The emission reduction measures are selected by an optimization algorithm that assesses their impact on air quality, health exposure, implementation costs. Such optimization algorithms requires thousands of air quality assessments; in these cases, AQ systems cannot directly be used because of the computing time demand, so they provide tens to hundreds simulations processed to identify 'simple' emissions-AQ links (source-receptor relationships) able to capture the specific features of a region.

There is a need to establish an evaluation protocol in order to standardise and harmonise validation and uncertainty estimation methods in EU countries. Within an IAM framework model evaluation and uncertainty estimation is more regularly performed in air quality modelling, while it is not often applied in other IAM components such as for example in the case of HIA applications. Health effects of air pollution are not, often, fully integrated in IAM.

Operational and diagnostic evaluations are the methods preferred both in the case of modelling for the purpose of air quality planning as well as for research projects. For the purpose of air quality plans, expert judgement is also frequently used. Uncertainty propagation methodologies are also used, although not so often, to quantify confidence levels of air quality model results.

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. The mandatory use of modeling tools when developing AQP is something that has to be seriously considered. Synergies among measures defined at different scales have to be taken into account when designing CAFE strategies and policies have to be comprehensively developed.

It is also important and well-timed to disseminate, promote and advice the use of IA models at the urban scale in order to facilitate decision-making regarding the most cost-effective air pollution mitigation measures. In this scope developing and testing methodologies to treat uncertainty in IA modeling is also needed.

6. References

van Aardenne, J. (2002) Uncertainties in emission inventories, Ph.D. Thesis. Wageningen University - TNO Institute of Environmental Sciences.

Amann, M., Bertok, I., Borken-Kleefeld, J., Cofala, J., Heyes, C., Höglund-Isaksson, L., Klimont, Z., Nguyen, B., Posch, M., Rafaj, P., Sandler, R., Schöpp, W., Wagner, F., Winiwarter, W. (2011) Cost-effective control of air quality and greenhouse gases in Europe: modelling and policy applications. Environmental Modelling & Software, 26, 1489-1501.

Appel, K.W, Gilliam, R.C., Davis, N., Zubrow, A., Howard, S.C. (2011) Overview of the atmospheric model evaluation tool (AMET) v1.1 for evaluating meteorological and air quality models. Environmental Modelling & Software, 26, 434-443.

Belis, C., Karagulian, F., Larsen, B., Hopke, P. (2013) Critical review and meta-analysis of ambient particulate matter source apportionment using receptor models in Europe. Atmospheric Environment, 69, 94-108.

Beverland, I.J., Cohen, G.R., Heal, M.R., Carder, M., Yap, C., Robertson, C., Hart, C.L., Agius, R.M. (2012) A comparison of short-term and long-term air pollution exposure associations with mortality in two cohorts in Scotland. Environ Health Perspect, 120(9), 1280-5.

Borrego, C., Sá, E., Carvalho, A., Sousa, J., Miranda, A.I. (2012) Plans and Programmes to improve air quality over Portugal: a numerical modelling approach. International Journal of Environment and Pollution, 48(1/2/3/4), 60-68.

Briggs, D., Sabel, C., Lee, K. (2009) Uncertainty in epidemiology and health risk and impact assessment. Environmental Geochemistry and Health, 31(2), 189-203

Brunekreef, B., Hoek, G. (2000) Invited commentary - Beyond the body count: air pollution and death. American Journal of Epidemiology, 151 449-51.

Builtjes, P., Jörß, W., Stern, R., Theloke, J. (2010) Particle reduction strategies PAREST (Final Report). FKZ 206 43 200/01. Contracting authority: German Federal Environment Agency.

Carslon, D., Haurie, A., Vialb, J-P., Zacharyc, D.S. (2004) Large-scale convex optimization methods for air quality policy assessment. Automatica, 40, 385–395.

Carnevale,C., Pisoni, E., Volta, M. (2007) Selecting effective ozone exposure control policies solving a two-objective problem. Ecological Modelling, 204, 93–103

Carnevale, C., Finzi, G., Pisoni, E., Volta, M. (2011) Minimizing external indirect health costs due to aerosol population exposure: a case study from Northern Italy. Journal of Environmental Management, 92, 3136-3142.

Carnevale, C., Finzi, G., Pisoni, E., Volta, M., Guariso, G., Gianfreda, R., Maffeis, G., Thunis, P., White, L., Triacchini, G. (2012) An integrated assessment tool to define effective air quality policies at regional scale. Environmental Modelling and Software, 38, 306–315.

Chang, J.C., Hanna S. (2004) Air quality model performance. Meteorology and Atmospheric Physics, 87,167–196

Coll, I., Lasry, F., Fayet, S., Armengaud, A., Vautard, R. (2009) Simulation and evaluation of 2010 emission control scenarios in a Mediterranean area. Atmospheric Environment, 43, 4194-4204.

Cuvelier C., Thunis P., Vautard R., Amann M., Bessagnet B., Bedogni M., Berkowicz R., Brandt J., Brocheton F., Builtjes P., Carnavale C., Copalle A., Denby B., Douros J., Graf A., Hellmuth O., Honoré C., Hodzic A., Jonson J., Kerschbaumer A., de Leeuw F., Minguzzi E., Moussiopoulos N., Pertot C., Peuch V.H., Pirovano G., Rouil L., Sauter F., Schaap M., Stern R., Tarrason L., Vignati E., Volta M., White L., Wind P., Zuber A. 2007. CityDelta: a model intercomparison study to explore the impact of emission reductions in European cities in 2010. Atmospheric Environment, 41(1), 189-207.

Davison, S., van den Elshout, S., Wester, B. (2011) Integrated Urban Emission Inventories, CiteAIRII, Common Information to European Air, Interreg IVC Programme (http://www.citeair.eu/fileadmin/Deliverables_and_documents/Guidebook_Integrated_Emission_Inventories_-_final.pdf) accessed 25/04/2013.

DEFRA – Department for Environment, Food and Rural Affairs (2010) 2010 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors.

Denby, B., Larssen, S. , Builtjes, P., Keuken, M.,; Sokhi, R., Moussiopoulos, N., Douros, J., Borrego, C., Costa, A. M., Pregger, T. (2011) Recommendations for the spatial assessment of air quality resulting from the FP6 EU project Air4EU. International Journal of Environment and Pollution, Vol. 44, No. 1-4, 2011, p. 128-138.

Denby, B., Georgieva, E., Larssen, S., Guerreiro, C., Li, L., Douros, J., Moussiopoulos, N., Fragkou, L., Gauss, M., Olesen, H., Miranda, A.I., Dilara, P., Thunis, P., Lappi, S., Rouil, L., Lükewille, A., Querol, X., Martin, F., Schaap, M., van den Hout, D., Kobe, A., Silibello, C., Vincent, K., Stedman, J., Gonçalves, M., Pirovano, G., Volta, M., van Pul, A., González Ortiz, A., Roberts, P., Oettl, D., Jericevic, A. (2010) Guidance on the use of models for the European Air Quality Directive A working document of the Forum for Air Quality Modelling in Europe FAIRMODE ETC/ACC report Version 6.2 (http://fairmode.ew.eea.europa.eu/fol429189/forums-guidance/model_guidance_document_v6_2.pdf) accessed on 25/04/2013.

D'Elia, I., Bencardino, M., Ciancarella, L., Contaldi, M., Vialetto, G. (2009) Technical and Non-Technical Measures for air pollution emission reduction: The integrated assessment of the regional Air Quality Management Plans through the Italian national model. Atmospheric Environment, 43, 6182-6189.

Dennis, R., Fox, T., Montse Fuentes, Gilliland, A., Hanna, S., Hogrefe, C., Irwin, J., Rao, ST., Scheffe, R., Schere, K., Steyn, D., Venkatram, A. (2010) A Framework for evaluating regional-scale numerical photochemical modeling systems. Environ Fluid Mech (Dordr), 10(4), 471–489.

De Ridder K., Lefebre F., Adriaensen S., Arnold U., Beckroege W., Bronner C., Damsgaard O., Dostal I., Dufek, J., Hirsch J., IntPanis L., Kotek Z., Ramadier T., Thierry A., Vermoote S., Wania A., Weber C. (2008) Simulating the impact of urban sprawl on air quality and population exposure in the German Ruhr area. Part I: reproducing the base state. Atmospheric Environment, 42, 7059-7069.

EEA – European Environment Agency (2009), EMEP EEA air pollutant emission inventory guidebook (http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009).

EEA - European Environment Agency (2011) MDS — Model Documentation System' (http://acm.eionet.europa.eu/databases/MDS/) accessed 25/04/2013.

EEA - European Environment Agency (2012) Air Quality in Europe, 2012 report, EEA report No 4/2012, Copenhagen.

FAIRMODE (2010) Background document on the emission needs at local scale (http://fairmode.ew.eea.europa.eu/fol404948/sg3_background_document_oct10_draft.pdf) accessed 25/04/2013.

Favez, O., El Haddad, I., Piot, C., Boréave, A., Abidi, E., Marchand, N., Jaffrezo, J.L., Besombes, J.L., Personnaz, M.B., Sciare, J., Wortham, H., George, C., D'Anna, B. (2010) Inter-comparison of source apportionment models for the estimation of wood burning aerosols during wintertime in an Alpine city (Grenoble, France). Atmospheric Chemistry and Physics, 10, 5295–5314.

Fragkou, L., Douros, J., Moussiopoulos, N., Belis, C. (2012) Review of the current evaluation methodologies used for source apportionment applications in EU countries. Forum for Air Quality Modelling in Europe FAIRMODE WG2, SG2 report.

Gasser, M., Riediker, M., Mueller, L., Perrenoud, A., Blank, F., Gehr, P., Rothen-Rutishauser, B. (2009) Toxic effects of brake wear particles on epithelial lung cells in vitro. Particle and Fibre Toxicology, 6, 30.

Giannouli, M., Kalognomou, E.A., Mellios, G., Moussiopoulos, N., Samaras, Z., Fiala, J. (2011) Impact of European emission control strategies on urban and local air quality. Atmospheric Environment, 45, 4753-4762.

van Gijlswijk, R., Coenen, P., Pulles, T., van der Sluijs, P. (2004) Uncertainty Assessment of NOx, SO2 and NH3 Emissions in the Netherlands. TNO and Copernicus Institute Research Report.

Guariso, G., Pirovano, G., Volta, M. (2004) Multi-objective analysis of ground-level ozone concentration control. Journal of Environmental Management, 71, 25–33.

HEI - Health Effects Institute (2013) Understanding the health Effects of Air Pollution: Recent Advances to Inform EU Policies. Workshop report, Brussels, January 2013.

Hogrefe, C., Rao, S.T. (2001) Demonstrating attainment of the air quality standards: integration of observations and model predictions into the probabilistic framework. J Air Waste Manag Assoc., 51(7), 1060-72.

Hurley, F., Hunt, A., Cowie, H., Holland, M., Miller, B., Pye, S., Watkiss, P. (2005) Methodology for the cost-benefit analysis for CAFE. Volume 2: Health impact assessment. Oxon: AEA Technology Environment, 2005.

IPCC – Intergovernmental Panel on Climate Change (2006) IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan.

Jaarsveld, Van J.A. (2004) The Operational Priority Substances Model. Report nr 500045001/2004, RIVM, Bilthoven, The Netherlands

Jerrett, M., Burnett, R. T., Pope, C. A., Ito, K., Thurston, G., Krewski, D., Shi, Y., Calle, E. (2009). Long-term ozone exposure and mortality. The New England Journal of Medicine, 360(11), 1085–95.

Jörß, W., Handke, V. (2010) Unsicherheiten der PAREST-Referenz-Emissionsdatenbasis. PAREST - Particle Reduction Strategies Forschungs- und Entwicklungsvorhaben im Auftrag des Umweltbundesamtes.

Juda-Rezler, K. (2004) Risk assessment of airborne sulphur species in Poland. Air Pollution Modelling and Its Application XVI. Eds. C. Borrego and S. Incecik, Hardbound: Kluwer Academic/Plenum Publishers, 19-27.

Karagulian, F., Belis, C. (2012) Enhancing source apportionment with receptor models to foster the air quality directive implementation. International Journal of Environmental Pollution, 50, 190–199

Karvosenoja, N., Klimont, Z., Tohka, A., Johansson, M. (2007) Cost-effective reduction of fine particulate matter emissions in Finland. Environ. Res. Lett. 2, 044002.

Kiesewetter, G., Borken-Kleefeld, J., Schöpp, W., Heyes, C., Bertok, I., Thunis, P., Bessagnet, B., Terrenoire, E., Amann, M. (2013) TSAP Report 9: Modelling compliance with NO2 and PM10 air quality limit values in the GAINS model. Service Contract on Monitoring and Assessment of Sectorial Implementation Actions (ENV.C.3/SER/2011/0009).

Lefebvre, W., Fierens, F., Trimpeneers, E., Janssen, S., Van de Vel, K., Deutsch, F., Viaene, P., Vankerkom, J., Dumont, G., Vanpoucke, C., Mensink, C., Peelaerts, W., Vliegen, J. (2011) Modeling the effects of a speed limit reduction on traffic-related elemental carbon (EC) concentrations and population exposure to EC. Atmospheric Environment, 45, 197-207.

Mediavilla-Sahagun, A., H. ApSimon (2013) Urban scale integrated assessment of options to reduce PM10 in London towards attainment of air quality objectives. Atmospheric Environment, 37, 4651–4665

Moussiopoulos, N., Douros, J., Reis, S., Friedrich, R. (2005) Merlin: the study of urban air quality in 20 European cities. In: Proceedings of the ninth International Conference on Environmental Science and Technology. pp. 1044–1049.

Oxley, T., ApSimon, H., Dore, A., Sutton, M., Hall, J., Heywood, E., Gonzales del Campo, T., Warren, R. (2003) The UK Integrated Assessment Model, UKIAM: A national scale approach to the analysis of strategies for abatement of atmospheric pollutants under the Convention on Long-Range Transboundary Air Pollution. Integrated Assessment, 4, 236-249

Oxley, T., ApSimon, H. (2007) Space, time and nesting Integrated Assessment Models. Environmental modelling and software, 22, 1732–1749.

Pisoni, E., Carnevale, C., Volta, M. (2009). Multi-criteria analysis for PM10 planning. Atmospheric Environment, 43, 4833-4842.

Pope, C., Dockery, D. (2006). Health effects of fine particulate air pollution: lines that connect. Journal of the Air & Waste Management Association, 56(6), 709–42.

Rabl, A. (2003) Interpretation of air pollution mortality: Number of deaths or years of life lost? Journal of the Air & Waste Management Association, 53, 41-50

Riediker, M., Gasser, M., Perrenoud, A., Gehr, P., Rothen-rutishauer, B. (2008) A system to test the toxicity of break wear particles. Zurich, Switzerland: 12th International ETH-conference on combustion generated nanoparticles.

Syri, S., Karvosenoja, N., Lehtilä, A., Laurila, T., Lindfors, V., Tuovinen, J-P. (2002) Modeling the impacts of the Finnish Climate Strategy on air pollution. Atmospheric Environment, 36, 3059-3069.

Tainio, M. (2009) Methods and uncertainties in the assessment of the health effects of fine particulate matter (PM2.5) air pollution. National Institute for Health and Welfare (THL) and Faculty of Natural and Environmental Science at Kuopio University.

Tainio, M., Tuomisto, J.T., Pekkanen, J., Karvosenoja, N., Kupiainen, K., Porvari, P., Sofiev, M., Karppinen, A., Kangas, L., Kukkonen, J. (2010) Uncertainty in health risks due to anthropogenic primary fine particulate matter from different source types in Finland. Atmospheric Environment, 44(17), 2125-2132.

Thunis, P., Rouïl, L., Cuvelier, C., Stern, R., Kerschbaumer, A., Bessagnet, B., Schaap, M., Builtjes, P., Tarrason, L., Douros, J., Moussiopoulos, N., Pirovano, G., Bedogni, M. (2007) Analysis of model responses to emission-reduction scenarios within the CityDelta project. Atmospheric Environment, 41, 208-220.

Thunis, P., Georgieva, E., Pederzoli, A. (2012) A tool to evaluate air quality model performances in regulatory applications. Environmental Modelling & Software, 38, 220–230.

UNECE (2002) Progress Report Prepared by the Chairman of the Task Force on Integrated Assessment Modelling, United Nations Economic Commission for Europe, Geneva, Switzerland.

Vautard, R., Builtjes, P., Thunis, P., Cuvelier, C., Bedogni, M., Bessagnet, B., Honoré, C., Moussiopoulos, N., Pirovano, G., Schaap, M., Stern, R., Tarrason, L., Wind, P. (2007) Evaluation and intercomparison of ozone and PM10 simulations by several chemistry transport models over four European cities within the CityDelta project. Atmospheric Environment, 41, 173–188

Viana, M., Kuhlbusch, T., Querol, X., Alastuey, A., Harrison, R., Hopke, P.K., Winiwarter, W., Vallius, M., Szidat, S., Prévôt, A., Hueglin, C., Bloemen, H., Wåhlin, P., Vecchi, R., Miranda, A.I., Kasper-Giebl, A., Maenhaut, W., Hitzenberger, R. (2008) Source apportionment of particulate matter in Europe: A review of methods and results. Journal of Aerosol Science, 39(10), 827–849.

Vinuesa, J-F., Mirabel, Ph., Ponche, J-L. (2003) Air quality effects of using reformulated and oxygenated gasoline fuels blends: application to the Strasbourg Area. Atmospheric Environment, 37, 1757-1774.

Vlachokostas, Ch., Achillas, Ch., Moussiopoulos, N., Hourdakis, E., Tsilingiridis, G., Ntziachristos, L., Banias, G., Stavrakakis, N., Sidiropoulos, C. (2009) Decision support system for the evaluation of urban air pollution control options: Application for particulate pollution in Thessaloniki, Greece. Science of the Total Environment, 407, 5937–5938.

Vlachokostas, C., Achillas, C., Moussiopoulos, N., Banias, G. (2011) Multicriteria methodological approach to manage urban air pollution. Atmospheric Environment, 45, 4160–4169.

Werner, S., Samaali, M., Ponche, J-L. (2005) Determination of uncertainties in emissions inventories at regional scale : application to the ESCOMPTE emission inventory. Marseilles Final ESCOMPTE Workshop Feb. 2-4, 2005, Marseille France.

Werner, S. (2009) Optimisation des cadastres d'émissions : estimation des incertitudes, détermination des facteurs d'émissions du « black carbon » issu du trafic routier et estimation de l'influence de l'incertitude des cadastres d'émissions sur la modélisation : application aux cadastres ESCOMPTE et Nord-Pas-de-Calais. Thèses de doctorat, Université de Strasbourg.

WHO – World Health Organization (2003). Health aspects of air pollution with particulate matter, ozone and nitrogen dioxide. Report on a WHO working group, Bonn 13-15 January 2003. Copenhagen, WHO.

Zachary, D.S., Drouet, L., Leopold, U., Aleluia Reis, L. (2011) Trade-offs between energy cost and health impact in a regional coupled energy–air quality model: the LEAQ model. Environmental Research Letters, 6, 1–9.