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Applying integrated assessment methodologies to air quality plans: Two European cases

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ABSTRACT

Air pollution Integrated Assessment Models (IAM) can be used for determining how emissions should be reduced to improve air quality and to protect human health in a cost-efficient way. The application of IAM is also useful to spread information to the general public and to explain the effectiveness of proposed Air Quality Plans. In this paper, the application of the RIAT+ system to determine suitable abatement measures to improve the air quality at a regional/local level is presented for two European cases: the Brussels Capital Region (Belgium) and the Porto Urban Area (Portugal). Both regions are affected with PM10 or NO_2 concentrations that exceed the limit values specified by the European Union legislation. To properly assess air quality abatement measures a surrogate model was used, allowing the implementation of an efficient optimization procedure. This model is derived in both cases through a set of simulations performed using a Chemistry Transport Model fed with different emission reduction scenarios. In addition, internal costs (due to the implementation of emission reduction measures) and external costs (due to population exposure to air pollutant concentrations) of policy options were considered. The application of this integrated assessment modelling system in scenario (Brussels case) and optimization (Porto) modes contributes to identifying some advantages and limitations of these two approaches and also provides some guidance when urban air quality has to be assessed.
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1. Introduction

European Union Member States (EU-MS), in the last decade, have developed urban air quality plans applying a wide range of different modelling methods to assess the effects of local and regional emission abatement policy options on air quality and human health (Borrego et al., 2012; Carnevale et al., 2011; Cuvelier et al., 2007; Lefebvre et al., 2011; Mediavilla-Sahagún and Apsimon, 2003, 2006). In the scope of the APPRAISAL EU FP7 project a review of air quality plans developed by the EU-MS and their assessment practices has been done (Thunis et al., 2016) aiming to identify methodologies and their limitations and to propose possible key areas to be addressed by research and innovation on the basis of this review. A structured online database of methodologies has been developed in collaboration with experts involved in the design of air quality plans (AQP) and Thunis et al. (2016) summarize the main outcomes of this database contents. Current practices vary widely between member-states and between the different administrative levels at which the assessment is undertaken, but there is a general need for more 'integrated' approaches, namely for the use of Integrated Assessment Modelling (IAM), which bring together air quality, health and cost-benefit aspects in the current assessment methodologies for air quality plans.

At the European scale, IAM have been developed in the recent years to provide a technical base for intergovernmental negotiations in a structured way. In the context of the United Nation Economic Commission for Europe (UNECE)'s Convention on Long Range Transboundary Air Pollution (CLRTAP), the integrated assessment model RAINS/GAINS (Wagner et al., 2007) has been extensively used to determine cost-efficient policies to reduce emissions and achieve EU-wide targets for various air quality

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indicators. Furthermore, IAM developed at the European scale, have been adapted to the national scale to be used to optimize emission reductions, e.g. the RAINS-Italy (D'Elia et al., 2009), the RAINS-Netherlands (Aben et al., 2005), the FRES-Finland (Karvosenoja, 2008), or the AERIS (Vedrenne et al., 2015) applied to Spain and Portugal. The USIAM (Mediavilla-Sahagún and Apsimon, 2006), the OTELLO (Comes et al., 2010) and the RIAT+ (Carnevale et al., 2012a) models were specifically developed to address regional and urban areas, but a more extended use of IAM in the scope of AQP would better support policy-makers in their definition of air quality improvement measures.

Aiming to support stakeholders with answers to questions related to the choice of an integrated assessment (IA) modelling tool, its setup and the evaluation of its outputs, a state of the art guidance document on IA applications was prepared in the scope of the APPRAISAL EU FP7 project (APPRAISAL, 2015a). The proposed design for an IAM is focused on the Driver/Pressure/State/Impact/Response (DPSIR) scheme put forward by the European Environment Agency (EEA, 2011) for describing the interactions between society and environment. The DPSIR building blocks were mapped onto the IAM elements as described by Viaene et al. (2016), namely: (i) Driving forces – the key activities that result in pollutant emissions; (ii) Pressures – the pollutant emissions; (iii) State – the air quality; (iv) Impacts – the consequences of the air quality for human exposure and health impacts and for environment; and (v) Responses – the measures that are available to reduce the impacts. The choice of abatement measures (responses) could be the beginning of the process with a clear link to the main activity sectors (drivers) and therefore to related emissions (pressures), which are converted to air quality (state) and finally to impacts.

This guidance was tested by applying an IAM tool to two test cases: one for the Brussels Capital Region in Belgium and the other to the region of Porto in the North of Portugal. This paper aims to present the main results from the application of the guidance recommendations to these two case studies, identifying limitations and future needs.

2. Brussels and Porto case studies

Within IAM two different pathways for identifying the appropriate abatement measures to be taken can be distinguished: (i) expert judgment/source apportionment or scenario analysis, and (ii) optimization approach. The first pathway is mainly used nowadays to design AQP at regional/local scale (Viana et al., 2008; Karagulian and Belis, 2012). Emission reduction measures are selected on the basis of expert judgment or source apportionment and then they are tested (usually) through simulations by an air quality model. This approach does not guarantee that cost-effective measures are selected, and only allows for “ex-post evaluation” of impacts and costs. Optimization computes the most cost-effective measures for air quality improvement, by solving a minimization/maximization problem. In other words, the approach allows for the computation of the most efficient set of technical (i.e. end-of-pipe) and non-technical (i.e. behavioural) measures to be encouraged and/or introduced to reduce pollution, explicitly considering their impacts and costs. In this section, the application of a scenario and an optimization approach is described. The scenario approach was applied to the Brussels case study and the optimization one to the Porto case study. Both case studies are based on the use of the RIAT+ IA system.

2.1. The RIAT+ system

RIAT+ (Carnevale et al., 2014) is an IA tool designed to help regional decision makers select air pollution reduction policies that improve the air quality at minimum costs. Both decision pathways (scenario analysis and optimization) can be selected within RIAT+. Its application to the solution of a decisional problem was based on the scenario approach, for the Brussels Capital Region in Belgium, and on the optimization mode, for the region of Porto in the North of Portugal. For both cases the decisional problem was the cost-efficient improvement of air quality levels to accomplish the 2008 EU Air Quality Directive limit-values.

The main inputs for RIAT+ are the emissions, a database containing details on the emission reduction efficiency, costs of available emission abatement measures (technical and non-technical), and a surrogate model that can calculate the effect of a set of selected abatement measures on an air quality indicator (AQI). The RIAT+ inputs structure can be associated to the DPSIR framework. The emissions database covers the Drivers and Pressures blocks and the surrogate model allows estimating the State in terms of air quality.

The default RIAT+ database with abatement technologies available for different macro-sectors (e.g. non-industrial combustion and transport) is the same as the one that was derived from GAINS Europe in the frame of the OPERA LIFE+ project (Carnevale et al., 2012a). This database includes data related to the different emission activities (unabated emission factor, activity level . . .) and technology details (removal efficiency, potential application rate, unit cost . . .). The GAINS database (Amann et al., 2011) contains activity data for the years 2010, 2015, 2020 and 2025. The year 2010 has been chosen as the reference year for both case studies, which is closest to the year used for the regional emission inventories (2009).

In the measure database, the CLE level (Current Legislation) is the level of application rates (the degree of implementation of a technology) that reflects the requirements of the current legislation. MFR (Maximum Feasible Reduction) is the level of application rates that reflects the maximum physically plausible application degree of a technology. The GAINS database provides for each measure/technology the degree of potential application (potential application rate) used to compute the MFR scenario.

Since the optimization process may require thousands of AQI computations to determine the optimal set of measures needed to reduce an indicator below a given certain level at minimum cost, a Chemical Transport Model (CTM) is not a direct option due to its high computational time. This is why the other important component of the IA system is the surrogate model linking precursor emissions and pollutant concentrations/AQI. This can be as simple as a linear relationship between emission and concentration/AQI or as complex as a non-linear relationship that could better reproduce the non-linearity of secondary pollutants generation. In the case of RIAT+, these non-linear relationships, linking emissions and air quality indices, consist of Artificial Neural Networks (ANN) trained to replicate the results of CTM simulations (Carnevale et al., 2012b). For the surrogate model training phase, a limited set of CTM calculations is performed. This set is representative of the possible emission variability and corresponding concentrations/AQI that can be encountered when applying the IAM. The process of selecting the emission scenarios that should be simulated by a CTM, in order to produce the training data set, is typically referred to as the ‘Design of Experiment’. These simulations have to be limited in number due to high computational time of the deterministic model, but they also must be able to represent, as closely as possible, the cause-effect relation between precursor emissions and the various considered AQI.

In this work, for both test cases, non-linear surrogate models based on ANN have been preferred to linear models, since these studies are focused on secondary PM10 concentration reduction, whose generation involves non-linear processes taking place in atmosphere.

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