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A TOOL TO SUPPORT EMISSION REDUCTION PLANNING AT REGIONAL SCALE

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Abstract: Tropospheric pollutants originate from complex chemical reactions and physical processes involving precursor emissions, namely VOC, NO_x, NH₃, primary PM and SO₂. Decision makers should thus develop reduction plans of precursors emissions to fulfil national and international commitments, such as EU directive 2008/50, minimizing the implementation costs of such plans. The paper presents the design of the Regional Integrated Assessment Tool (RIAT), a Decision Support System implementing a multi-objective methodology for Air Quality planning.

Key words: *Integrated Assessment Modelling, Decision Support System, Air Quality Planning.*

INTRODUCTION

In recent years, integrated assessment models (IAMs) at continental scale, namely RAINS/GAINS (Greenhouse Gas and Air Pollution Interactions and Synergies), described in Amann *et al.*, (2004), have been adapted to the national scale. RAINS-Italy by ENEA (Zanini *et al.*, 2005), RAINS-Netherlands (Hettelingh *et al.*, 2001), FRES-Finland (Johansson *et al.*, 2001) or UK-IAM (Oxley *et al.*, 2007) are examples of this process. These models implement the same approach as continental ones and thus are not well suited to support the Air Quality Managers at the local/regional scale. Indeed, most of the air quality agencies nowadays lack tools for an efficient planning and are limited to the use of simpler approaches (scenarios analysis). The objective of the work reported in this paper is to fill this gap by designing an enhanced methodology and implementing a tool to identify efficient local policies complying, on the one hand, with National and EU air quality standards and, on the other hand, with local emission and meteorological features, as well as financial, technological and social constraints. Therefore the proposed IAM is focused on local to meso-scale to interpret the specific features of the area, the meteorological and chemical conditions of the domain, the contribution of regional and local precursor emissions. The IAM solves a multi-objective (air quality, internal and external costs) optimization problem to select effective abatement strategies (Pisoni *et al.*, 2009). The decision variables are the emission abatement measures and the final solution provides the least costly mix of abatement measures needed to reach any desired value of air quality. Artificial neural networks are used to describe the nonlinear relations between precursor emissions reductions and an air quality index (AQI), that defines the air quality objective. These neural networks are trained to closely replicate the output of a complex long-term 3D deterministic multi-phase modelling system (Carnevale *et al.*, 2009), that would be too complex to be directly used within the optimization procedure. The internal costs are due to the implementation of emission reduction measures, while the external costs assess the damage due to pollution exposure of the population in the domain under analysis (Pisoni *et al.*, 2009b).

The design of this Regional Integrated Assessment Tool (RIAT), implementing the described methodology is presented in the paper. Its first application will be for Region Lombardia in Northern Italy (Figure 1), where severe secondary pollution episodes take place almost every year.

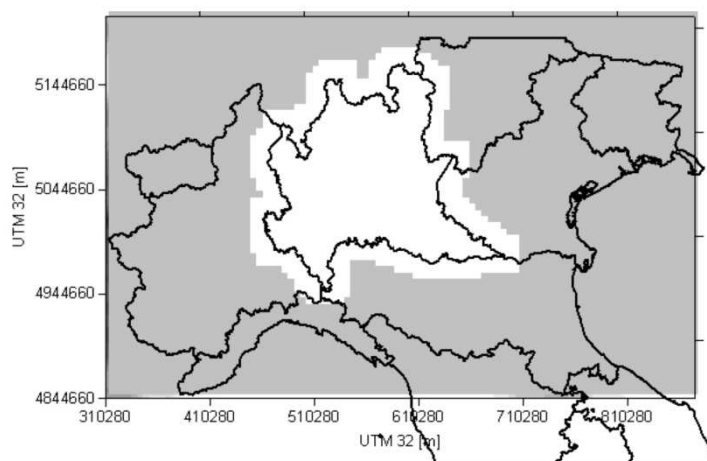


Figure 1. RIAT application domain.

THE RIAT DECISION SUPPORT SYSTEM (DSS)

RIAT is a multi-language DSS, developed as an open-source, stand-alone application with J2SE platform (Java 2 standard edition) for Microsoft Windows operating system.

The system (Figure 2) consists of:

- Four data interface procedures, that extract necessary data from a large set of input files, namely from technology database in GAINS, from current air quality plans (AQP), from the local emission inventory (EI), and from the output of the 3-D chemical and transport model (CTM) to develop approximated source-receptor (S-R) relationships.
- Four databases which are the output of the above procedures (geographical and gridded emissions, abatement measures, S-R models, plus information on the population exposure costs)
- Three internal procedures (gridding, optimization and output formatting)
- Five deliverable databases (emissions, abatement measures, AQIs, internal and external costs and log/lst files) that may also be represented in geographical terms.

AQPs represent reference conditions that the user can assume as starting points. They correspond for instance to the application of current legislation (CLE) as already planned by international agreements for some year in the future (e.g. application of all the abatement measures that will be compulsory in year 2015 with a certain removal efficiency), or to the maximum potential application of all the abatement technologies currently available. Though this plan represents the most expensive (and possibly unrealistic) solution, it is extremely important for the user since it defines the feasible range of air quality values, i.e. the environmental conditions that may be actually reached by defining some action on the area considered. It is clear in fact, that air pollution cannot be reduced below a certain level, both because of the influence of the surrounding emissions and because available technologies cannot zero emissions, unless the corresponding activities are closed (a decision not allowed within RIAT).

The data interface procedures

Interface procedures access external data i.e. data linked to but not included in RIAT. The interfaces available in the first implementation of the system for Lombardy region are the following:

- Interface RIAT- emission inventory. The aim of this interface is to compile the Lombardy Region emissions database INEMAR (INventario delle EMissioni in Aria, www.arpalombardia.it/inemar/inemarhome.htm) into the RIAT working format, providing emission for each considered pollutant, for each spatial unit (in the case of Lombardia, NUT4 - municipalities), for each type of emission source (point, area and gridded source) at the level of SNAP3 and fuel type.
- Interface RIAT- GAINS. This interface compiles GAINS measure/technology database into the RIAT working format, providing for each year removal efficiency (for each pollutant), application rate (under current legislation and potential for the different years), and unit cost.
- Interface RIAT- AQP. A specific RIAT internal loader developed in JAVA will allow uploading the input file containing a set of specific measures in the respective file format through both a worksheet interface and a classical GUI for single measures. New measures should respect previous measures format in terms of removal efficiency, application rate, reference cost-function and year considered (using or modifying an existing GAINS one or creating a new one through a specific module).
- Interface RIAT- CTM. This interface procedure extracts from CTM simulations the information needed to identify source receptor functions. This implementation uses TCAM (Carnevale *et al.* 2008) simulations run within the European POMI project (aqm.jrc.ec.europa.eu/POMI/), for the year 2005. A relative high number of emission scenarios and consequent AQI variations is needed to allow a robust identification of the neural S-R models.

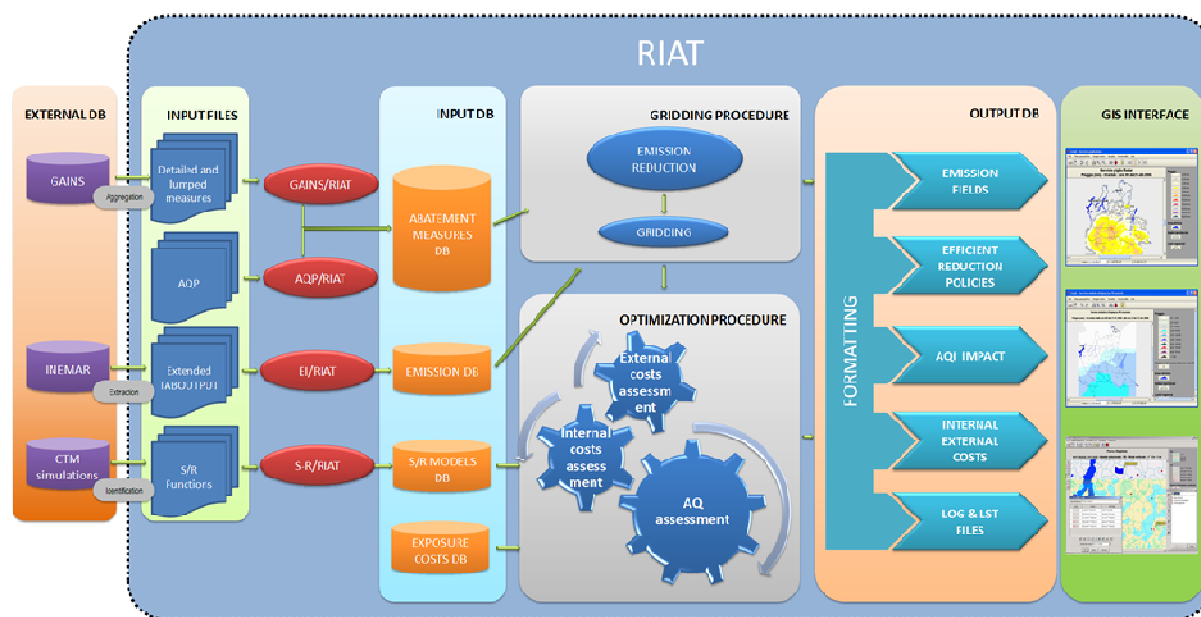


Figure 2. RIAT DSS flow-chart.

The user interface

The spatial domain, the AQI to be considered, the feasible abatement measures and all the other parameters that define the problem are set by the user through a graphical and menu driven interface (see figure 3). The user choices define also the specific content of the internal databases. For instance, the “Abatement measures” database contains, for each GAINS activity, the measures/technologies for abating emissions that the user wants to consider and possibly optimize. Each measure is characterized by a removal efficiency and unabated emission factor (per each pollutant, in case it may be effective on more than one), application rates (CLE and potential) as well as for various reference years (2005, 2010, 2015 and 2020 in the first implementation), and unit abatement costs. In quite the same way, the “Emission” database separates the emissions (point, area, or gridded) that the user wants to consider as the object of his/her decision and all the others that remain fixed at a given reference level (base case).

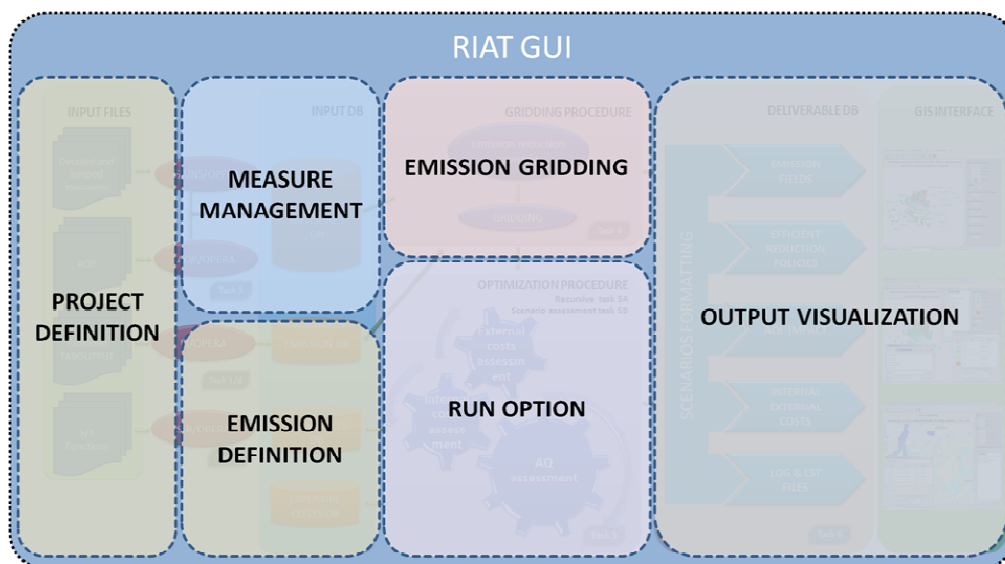


Figure 3. RIAT Graphical User Interfaces scheme.

The internal procedures

The *internal procedures* are the core of the system and consist of elaboration processes governed by the RIAT GUI. There are one pre-processor (EMISSION GRIDDING), the decision problem solver (OPTIMIZATION) and a post-processor (FORMATTING).

- RIAT interface with emission and technology databases (both GAINS and/or regional from AQP) is performed by the EMISSION GRIDDING pre-processor. It allows
 1. computing emission scenarios on the whole modelling domain and on the optimization domain (the part interested by regional policies)
 2. gridding the emissions and specifies an emission scenario in the optimization module format.
- The OPTIMIZATION module implements and solves a multi-objective problem aimed to select effective policies to control the primary and secondary pollutants population exposure while minimizing the policy implementation costs. Its final solution is thus a curve in the plane internal and/or external costs – AQI (the Pareto boundary), each point of which represents an efficient mix of emission abatement measures, defined in terms of prioritizing abatement sectors, penetration rate of reduction measures, internal (due to abatement measures implementation) and external (due to population exposure) costs and air quality improvements. The problem, as anticipated, can be solved for specific areas of the computational domain.

The following air quality indexes are assessed by the system according to the geographical areas considered: PM2.5 and PM10 yearly mean concentration, AOT40 and SOMO35 for ozone. Within the optimization, the relationships between the decision variables (precursor emission reductions) and the air quality index are simulated by the source-receptor models previously identified by processing the long-term simulations of the chemical transport model.

All the emission activities and reduction measures selected by the user are explicitly considered and the internal cost corresponds to the sum of each emission reduction measure costs.

The external costs due to the population morbidity and mortality are assessed following the EU ExternE methodology (www.externe.info).

- The FORMATTING post-processor standardizes deliverables produced by the optimizer to be visualized through the GIS output interface. The final RIAT outputs are the effective reduction measures and their application rate, the consequent emission scenarios, the optimized air quality indexes, the internal and external costs.

The output databases

Final deliverable databases are:

- EMISSION. It contains the optimized gridded annual emissions, sector and pollutants in a gridded format suitable for both AQ modelling and GIS visualization (Figure 4).
- POLICIES. It contains the optimized measures (technologies), their application rates and the consequent regional emission reduction.
- AQI. It contains the gridded air quality indexes obtained by the application of the chosen S-R on the reduced gridded emissions.
- COST. It contains the minimum internal costs obtained by applying cost functions on the reduced gridded emission and the external costs. The internal costs are calculated using data related to reduction measure unit cost, efficiency, and degree of implementation.
- LST&LOG files. It contains the description of the input and of the chosen procedures, the output and the possible warnings or errors encountered during computation. A special focus will be dedicated to check the correct computation of each procedure (e.g. mass consistency for gridding), so that the user could follow step by step the system calculations.

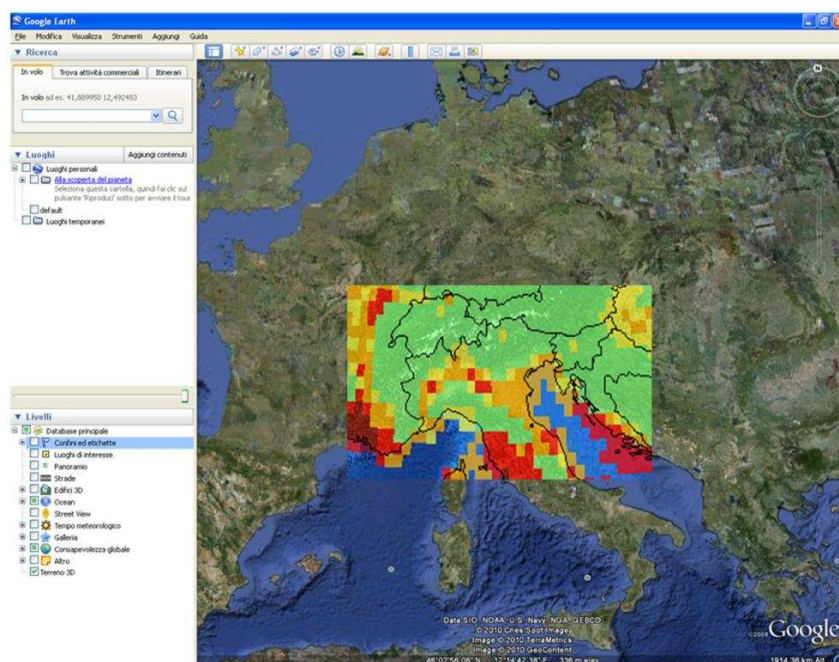


Figure 4. Example of gridded output in GIS visualization.

Software

The main software architectural choices are:

- Microsoft Windows operating system.
- J2SE (java 2 standard edition) platform – Java is probably the most popular open-source object-oriented programming language.
- FORTRAN developing language for data processing.
- MATLAB routines for optimization procedures, S-R model identification and simulation. Both these choices are completely transparent to the user that simply launches executable files from the interface without seeing how they have been developed.
- Apache DERBY for the databases - an open-source database implemented entirely in Java, fully transactional, secure, easy-to-use, standard-based (SQL, JDBC API, and Java EE).
- GIS interface based on GOOGLE Earth, providing the user with basic and well known GIS navigation functions and good cartographic information. Through GOOGLE Earth both gridded and isoline data can be visualized and analyzed.

RIAT is designed to guarantee:

- Modularity: each process, interface or database could be substituted (input and output defined format should obviously be respected).
- User friendliness: a continuous follow-up of user's choices is provided and appropriate warnings are issued in case of incoherency or selection of too complex paths (e.g. the request for a too complex optimization that may never converge or require extremely long execution times).
- Efficiency.
- Open-source approach.
- Multi-language approach: wording is stored in a separate file that can be easily changed.

CONCLUSIONS

For the first time, RIAT scales down IAMs typically working off-line for national and international negotiations to regional level. Additionally, it splits the overall computation into two phases: running off-line several CTM simulations and

calibrating, only once, simplified approximators; and then it uses these in an (almost) on-line optimization procedure, thus supporting discussion and evaluations in a completely different style.

Following the first implementation of RIAT in the Regione Lombardia area, the Joint Research Centre intends to proceed in applying the same methodology in other interested regions of Europe. In our opinion the implementation of such a specific application for regional cases has a great potential for application also in the context of the EU Air Quality Directive and may pave the way to a new approach to regional air quality management in the future.

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