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RIAT+: AN ADVANCED DECISION SUPPORT TOOL FOR REGIONAL AIR QUALITY PLANNING

Introduction

Air pollution is an environmental issue of major concern in Europe, as highlighted by the EU Thematic Strategy for air quality (COM 2005 446) and Directive 2008/50/EC on ambient air quality and cleaner air for Europe. Despite a general improvement in recent years, some regions in Europe still suffer pollutant levels that threaten human health and ecosystems. This is the case, for instance, of the Po Valley, located in Northern Italy, where high population and emission densities, and poor meteorological dispersion lead to severe levels of fine particulate matter ($PM_{2.5}$) and ozone concentrations, causing evident negative impacts. Due to the complexity of the phenomena involved in the formation and accumulation of these secondary pollutants in atmosphere, Decision Makers need effective computer tools enabling the assessment of the effectiveness of emission control policies for the environment, the economy and the society.

This has been the goal of OPERA project (LIFE09 ENV/IT/092) that defined a methodology and developed its implementation in a software tool, RIAT+, to support regional/local authorities in the definition, application and evaluation of air quality plans, devoted to the reduction of population exposure to PM_{10}, $PM_{2.5}$, NO_2 and O_3. The methodology to face this challenging problem can be interpreted as two decision pathways, within the classical DPSIR (Drivers-Pressures-State-Impacts-Responses) scheme:

- Scenario analysis. This is the approach mainly used nowadays to design the air quality plans at regional/local scale. Emission reduction measures (responses) are selected on the basis of expert judgment or Source Apportionment and then they are assessed through simulations of an air quality (state) model. This approach does not guarantee the cost-effectiveness of the chosen measures; costs and other impacts are mainly evaluated ex-post.

- Optimization. This pathway indicates the most cost-effective measures technical (end-of-pipe) and non-technical (energy efficiency and behavioural) for air quality improvement by solving an optimization problem to reduce pollution, explicitly considering their impacts and costs.

RIAT+ is an advanced and flexible integrated modelling environment that allows implementing both these approaches, including the maximization of the environmental benefits with fixed implementation costs, or the minimization of costs at fixed environmental benefits or the determination of the optimal trade-off between costs and environmental quality (Carnevale *et al.* 2012). Thanks to its open design, RIAT+ can be easily applied to different regions since it incorporates all the specific features of the area in the input datasets. As an example, this work reports the results of its application to Alsace, France, and Emilia-Romagna, Italy.

RIAT+ STRUCTURE

RIAT+ integrates tabular and geographic data, simulation and optimization models, graphical and geographical user interface, focusing on the regional scales (see Fig. 2) into a generic software environment that can be easily applied to different problem settings and to different regions.

The main input data for its application are:

- precursor emissions of local and surrounding sources;
- technical and non-technical abatement measures that can be actually applied;
- source-receptor (S/R) functions or models describing the relationship between precursor emissions and Air Quality indexes, influenced by local meteorology and prevailing chemical regimes.

S/R models are necessary since a full CTM (Chemical Transport Model) cannot be run in real time within an optimization procedure for its CPU time requirements, and thus it must be substituted by simpler relationships between emission sources and air quality indicators at the specific relevant receptor sites. Artificial Neural Networks - ANN are used as S/R models in the following applications since they can capture the non-linearity in the relationships between emissions and concentrations, with an acceptable CPU time (Carnevale *et al.* 2012a).

Peculiar characteristics of RIAT+ core system are:

- A multi-objective optimization problem solver, i.e. one or more air quality indicators (e.g. yearly PM_{10} average) are reduced in the policy application domain (the relevant portion of the area under study), minimizing the costs of emission reduction measures costs to obtain a desired air quality improvement. The solver is able to select and present to RIAT+ user the entire set of efficient abatement measures, in terms of application rates (i.e. penetration levels to be reached).

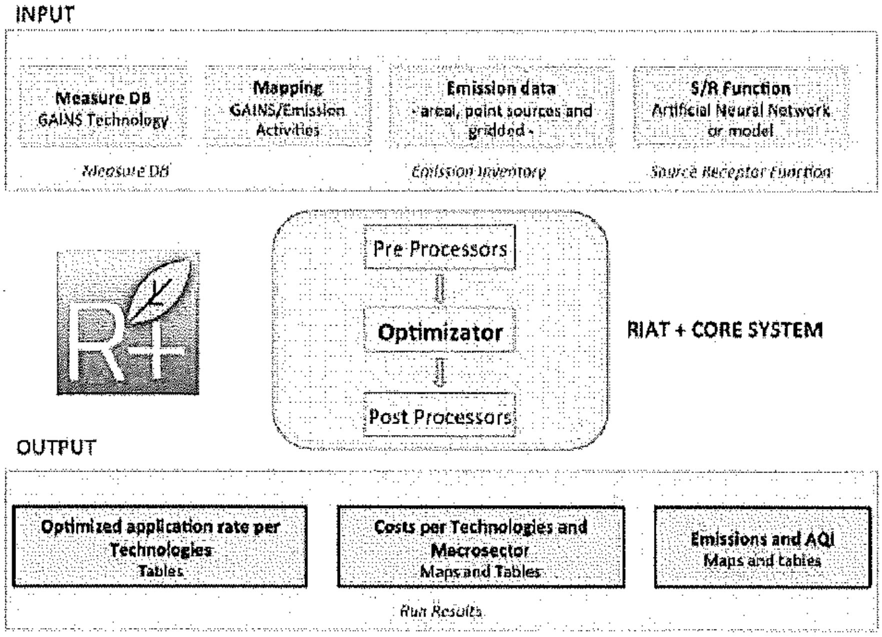

Fig. 1. – RIAT+ block diagram with I/O and the core system.

Different air quality indexes can be computed (yearly average of PM_{10}, $PM_{2.5}$, and NO_2, PM_{10} daily exceedances, AOT40, O_3 8hrs maximum); the overall social cost can be constrained to a specific value (cost-effectiveness approach) or can be split into different macrosectors; abatement measures can be limited to a specific policy application subdomain (e.g. urban areas); state-of-art technologies may be fixed for some years while older technology could be substituted; optimization can be limited to a subset of macrosector technologies; scenarios can be simulated fixing aggregated emissions or specific technologies.

Application to Alsace

Alsace is situated in north-eastern France, alongside Switzerland and Germany, in the geographical and historical region of the Upper Rhine Valley. The valley, embanked between the mountains of the Vosges and the Black Forest, creates winds that promote air pollution, with frequent temperature inversions in winter. Moreover, with its border location, Alsace is situated at Europe's economic crossroads around the Rhine. This generates a lot of traffic. It also hosts important industrial activities, varying from large industrial sites to small and medium enterprises. The industrial sites around Mannheim (North-East pattern, Germany) also contribute considerably to air pollution in Alsace. This particular configuration causes air pollution problems mainly along the traffic axes and in the three major cities (Strasbourg, Mulhouse, Colmar).

The main objectives of the current Alsace air quality plans are:

- Compliance with the NO_2 annual limit value (40 µg/m^3) and the PM_{10} daily limit value (50 µg/m^3 to be exceeded less than 35 days per year);
- Reduction of concentrations of $PM_{2.5}$ by 30% between 2010 and 2015.

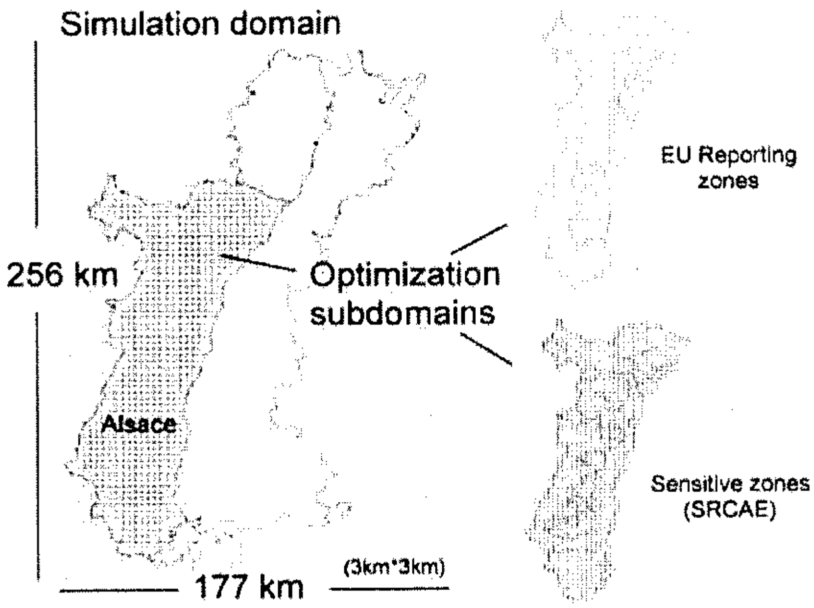

Fig. 2. – Alsace domain grid for simulation (left); subdomains for optimization (right) based on the EU reporting zones and on the sensitive zones

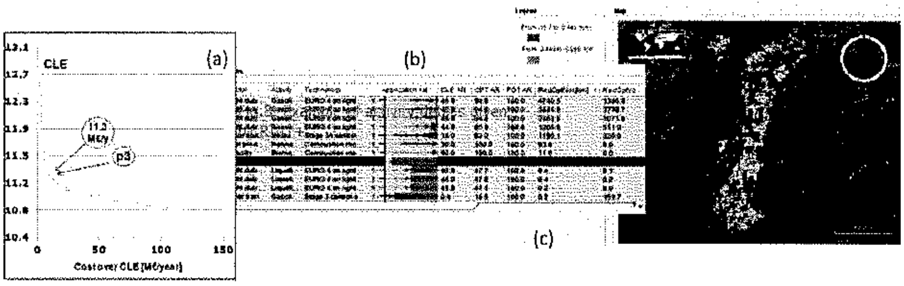

Fig. 3. – Results for the optimization of NO_2 (a), detail of abatement measures (b), and concentration reductions on the territory (c).

The gridded emissions were prepared using the tool MANAG'AIR (www.atmo-alsace.net). Air pollution has then been simulated for the year 2005 using WRF/CHIMERE (www. lmd.polytechnique.fr/chimere). Finally, air quality indicators (AQI) have been calculated and the neural networks trained and produced.

Different subdomains for optimization (Fig. 2) have been defined: the whole Alsace, the four "European reporting zones" and the so-called "sensitive zone", as defined in the SRCAE, representing the priority areas for air quality and enclosing about 29% of the territory and 63% of the population.

Example results for the optimization of the mean NO_2 concentration (in the sensitive zones, for the whole year) and its side-effects on NO_2 in winter, PM_{10}, $PM_{2.5}$ and ozone (SOMO35) are shown in Figure 3a. The Pareto curve (a curve providing the optimal solutions ranked by costs) shows possible combinations of reduction measures and their cost (Carnevale *et al.* 2014).

For point p3 of the Pareto curve, Figure 3b details that emission reductions mainly concern sector "8: other mobile sources", "7: road transport" and sector "1: combustion in energy and transformation industries". Costs (~11 M€/year above those requested by the Current Legislation) are mainly assigned to sectors 1 and 8. RIAT+ also shows the correspondent concentration reductions obtained on the territory (Fig. 3c).

Another example is the optimal reduction of PM_{10} concentrations in winter, for which RIAT+ shows that the most effective measures are:

- Better devices for wood-fired stoves
- Higher standard for agriculture and forestry mobile sources
- Spraying water at construction places
- Higher standard for railway mobile sources (diesel)
- High efficiency emission abatement system in fertilizer production

- High efficiency emission abatement systems in nonferrous metals production
- Higher standard on light duty vehicles
- Higher standard on light commercial trucks (diesel)
- Combustion modification on oil and gas industrial boilers & furnaces.

RIAT+ APPLICATION TO EMILIA ROMAGNA

Emilia-Romagna region is located in the south-west part of the Po Valley basin, where meteorological conditions, due to the low wind intensity, cause the stagnation of the air masses, associated with peak pollution episodes of PM during winters and high level of ozone during summers. The daily Limit Value for PM_{10} was exceeded every year since the enforcement of the EU directive (2005) despite a slow decreasing trend.

NO_2 annual limit value shows some exceedances mainly in the traffic stations. Ozone health and vegetation protection limit values are systematically exceeded in all the stations.

PM and ozone precursors are mainly due to road transport and combustion, and almost 60-65% of particulate matter is of secondary origin.

The results of model simulations of the current legislation scenario at 2020 (CLE 2020) show that the daily limit values for PM_{10} can be exceeded also in the future. For this reason Emilia-Romagna Region government adopted in December 2012 the guidelines for the elaboration of the Regional Air Quality Plan (PAIR2020) and approved the preliminary air quality plan document in July 2013. The emissions reduction target for PAIR2020 was assessed during the OPERA project by a cost-effectiveness analysis based on the implementation of the RIAT+ tool to the Emilia-Romagna domain (Fig. 4a).

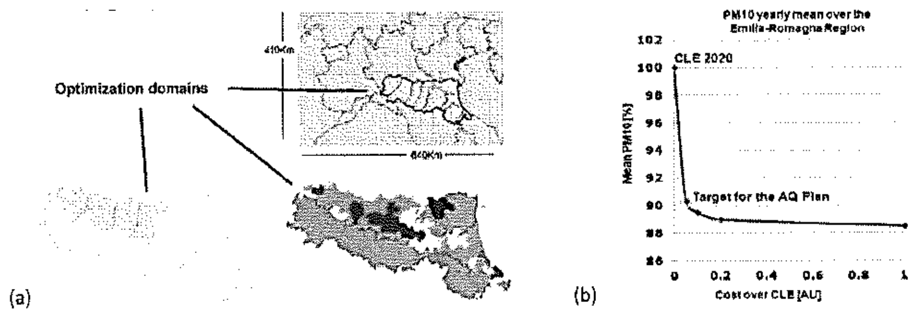

Fig. 4. – Emilia-Romagna optimization domains (a) and optimal PM_{10} yearly average concentrations policies (b).

The emission scenarios and the resulting air pollution simulations have been produced on a domain grid covering the Emilia Romagna and the surrounding areas, which influence the regional air pollution. The gridded emissions (year 2010) were prepared using the tool eFESTo. Air pollution concentrations have then been simulated for the year 2010 using NINFA (www.arpa.emr.it) to produce ANN S/R models.

RIAT+ has been applied to the optimization of the yearly PM_{10} average on the whole region, and the resulting Pareto curve is represented in Figure 4b. The vertical axis represents air quality as a spatial averaged over the whole domain in percentage reduction with respect to the CLE 2020 value (1st point in the Pareto curve), while the horizontal axis (costs) indicates the percentage increase beyond CLE 2020 scenario. Analysing, for instance, emission reduction corresponding to the target air quality values, it can be seen that a significant reduction of NH_3 should be reached acting on agriculture macrosector, while NO_x reduction should be obtained in the transport and other mobile sources macro-sectors. Actions on residential heating should be promoted to reduce a large part of primary PM_{10} emission.

The resulting PM_{10} yearly average concentration map of this optimal scenario is represented in Figure 5. The combination of several other different runs with single or multi-pollutant optimization lead to the following list of priority measures to be implemented in Emilia Romagna:

- energy efficiency measures in the residential sector including improved fireplaces

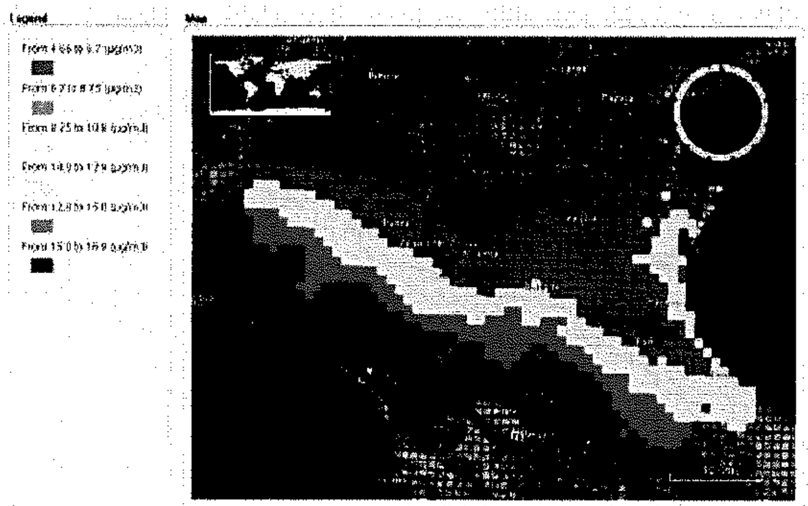

Fig. 5. – Average PM_{10} concentrations computed by RIAT+ (target point 2 of the Pareto curve in Fig. 4b).

- high efficiency oil and gas industrial boilers and furnaces in manufacturing industry
- replacement of old heavy and light duty diesel vehicles (i.e. Euro5 and Euro6), as well as an increase of the limited traffic zones and cycling paths
- replacement of oldest construction and agriculture vehicles
- Urea substitution in fertilizers and improved farming practices (low nitrogen feed, covered outdoor storage of manure...).

Concluding remarks

RIAT+ is an integrated software tool that has already been proved to effectively support regional air quality plans. Its flexibility allows a rapid deployment in different contexts and indeed its application to other regions has already been carried out (Alsace, France, and Lombardy, Italy) or is under way (Porto, Portugal; Brussels, Belgium) within the EU APPRAISAL project (FP7 303895, www.appraisal-fp7.eu). The software package can be freely downloaded from the OPERA project website (www.operatool.eu).

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