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Project MERLIN and Its Modeling Environment

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Abstract: *MERLIN was a project from the 5th EC framework program with the main aim – development of tools for multi-pollutant multi-effect assessment of the European air quality. Stock activity and measure databases, existing software tools and models and some efficient algorithms are combined in one model framework – an integrated assessment model.*

Keywords: *Multi-pollutant, multi-effect, integrated assessment model (IAM), measure-matrix approach, evolutionary algorithm (EA).*

Introduction

MERLIN was a project from the 5th EC framework program (EVG3-2000-00514). The aim of the project was the development of a computer-based model system to determine the bundle of air pollution control measures, that is capable of achieving compliance with air quality limit and target values (for emission, concentrations and deposition) for specific pollutants at least-costs. MERLIN means “Multi-pollutant, Multi-Effect Assessment of European Air Pollution Control Strategies: an Integrated Approach”. Within this multi-pollutant multi-effect framework, the reduction of ambient concentrations of tropospheric ozone, particulate matter, heavy metals, NOx, the emissions of greenhouse gases (GHG), as well as acid deposition and eutrophication was planned to be assessed. The instruments, developed in the frame of MERLIN, have to be applied and tested for compliance with the air quality limit values of the EC Air Quality Framework Directive (and its Daughter Directives), the EC National Emission Ceilings Directive, the UNECE critical loads for acid and nitrate deposition and the reduction targets agreed upon in the Kyoto Protocol.

When started in 2001, the project involved the following institutions: Institute of Energy Economics and the Rational Use of Energy (IER) – University of Stuttgart, Stuttgart, Germany (Co-ordinator); The Norwegian Meteorological Institute (DNMI) – Oslo, Norway; ECOFYS Energy and Environment – Utrecht, The Netherlands;

Institute for Ecology of Industrial Areas (IETU) – Katowice, Poland; Laboratory for Heat Transfer and Environmental Engineering (LHTEE) – University of Thessaloniki, Greece; University College London (UCL) – London, United Kingdom. At a later stage the project team was extended with the following participants: University of Ostrava - Energy Research Centre (ERC) – Ostrava, Czech Republic; National Institute of Meteorology and Hydrology (NIMH) – Sofia, Bulgaria; University 'Petroleum-Gas' of Ploiesti (UPG) – Ploiesti, Romania. The main aim of this paper is to provide some information about the project and its achievements.

The idea to create an Integrated Assessment Model (IAM) from new generation, and respectively for the project MERLIN, appears in accordance with the problems of the existing IAMs to reproduce in a realistic way the processes of multi-pollutant and multi-effect assessments. These problems are here described in "About the limitation in the use of single abatement cost curve". The MERLINs IAM framework is presented as "MERLINs environment". The main innovations in this IAM – measure-matrix approach for pollution reduction and use of the evolutionary algorithm in the optimization procedure are also described, but more detailed, in this part. Some results and conclusions are presented in "Summary and Results"

The project (previously designed for a duration of 3 years, but practically with two extensions) started with data collection (preparation of stock-activity and measure databases). The Bulgarian participation in MERLIN (and of the other assossiated countries) was connected mainly with this activity as well as with providing the project with different kind of additional information for the country. Modeling and assessment was planned to be conducted at all necessary levels, from atmospheric dispersion modeling on European, regional and urban scales to macroeconomic impact assessment of optimized control strategies for all relevant pollutants and the assessment of distributional effects and burden sharing issues. Besides, if applied to a base case and future trends within the project, the instrument developed should be designed to serve as a tool for policy support. It was also intended to establish a web-based scenario tool, able to adjust scenarios and create data basis, on which the optimization tools are run, respectively allowing to conduct case studies for individual measures, sectors, countries or pollutants on a manual basis. Due to time constraints it was impossible to perform some of the planned tasks and practically the work continues within the frameworks of other projects. The official end of the project was in October 2004.

1. About the limitations in the use of single abatement cost curve

Single abatement cost curves for one specific pollutant and a source sector or country are widely used in Integrated Assessment Models (IAMs). The main aim of this concept is to provide a function of costs and related emission levels in a computable way. These curves give a set of parameters for the optimization algorithm in order to identify the least-cost ways to achieve given reduction targets and to assess the overall costs of the strategies. In some cases the cost curves usually represent relationships between emissions and concentrations, such as source-receptor matrices. Typically the analysis considers the linear relationship between emissions and concentrations, respectively emissions and effects. In the case of one pollutant, the cost per unit of pollutant controlled by a specific measure, is easy to assess on the basis of information about activity types and economic and technical parameters of the abatements installations – measures are ranked by its unit costs or its marginal abatement costs.

The first difficulties appear when air pollution by tropospheric ozone comes into focus. The reason is that the relationship between emissions of ozone precursor substances NOx and Non-Methan Volatile Organic Componds (NMVOCs), and to some extent CO, is not linear. Most of the abatement measures affect the concentrations and deposition of several (primary and secondary) air pollutants. It has become clear that the simple addition of strategies that may be efficient for one pollutant/effect does not lead to an overall optimal pathway. Generating abatement cost curves as input to optimisation leads to an artificial constraint of the models that are applied to find optimal solutions for a given task. The reason for this is that when two or more pollutants are to be controlled the issue of allocating cost proportions to single pollutant cost curves is not yet trivial.

The limitations in the use of single abatement cost curves are obvious, particularly in the view of the correlations between different pollutants and effects, as indicated in Fig. 1 [3].

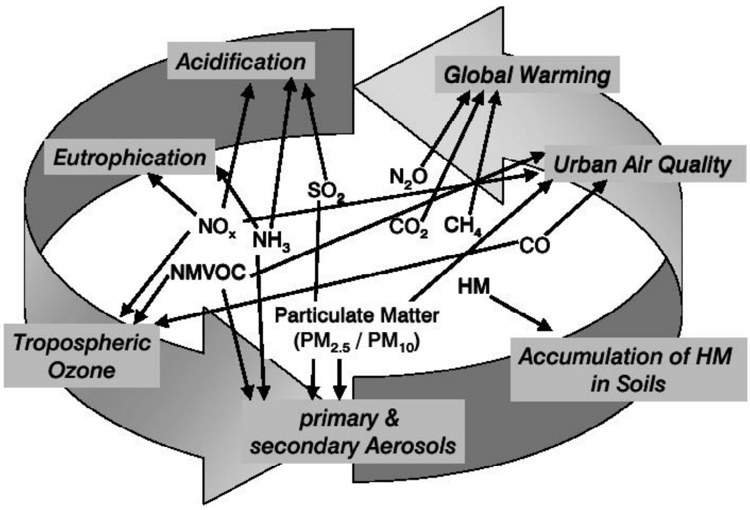

Fig. 1. Illustration of the multi-pollutant multi-effect problem

Thus, it becomes clear that an analysis that does not account for all the benefits of the measures will not result in an overal optimal strategy. Furthermore, synergy effects of the interconnected measures are not taken into account in single-pollutant/effect strategies, hence abatement costs are often overestimated in relation to the benefits achieved. That is why a new approach has to be taken that is able to reproduce the complex multi-pollutant multi-effect relations, but at the same time to be transparent, simple enough and to keep uncertainties to a minimum. Practically this means devising an IAM of new generation.

2. MERLIN's environment

2.1. Modeling framework

During the project MERLIN a set of models was created and combined in an IAM, which framework is sketched on Fig. 2.

The databases (SADB = Stock/Activity Database and MDB = Measure Database, including technical and non-technical measures) contain information for some target years (2000, 2010 and 2020). These databases are compiled for the EC and assossiated countries (EC25+) for different economic sectors (power sector, transport, industry, households) and are necessary to calculate emissions for all relevant sources (air pollutants and GHGs) and thus – the changes in emissions due to the implementation of measures and strategies. Further, chemical transport model (CTM) is used to calculate changes in concentrations and depositions resulting from changes in emissions. In this case the Eulerian model, called EMEP is used. The CTMs cannot be used directly for cost-effective (CEA) and cost-benefit (CBA) assessments since they require very long computing time. A feasible solution for this problem is to express the relation between emissions, concentrations and deposition in a parameterised way (based upon CTM model calculations) and to introduce these source-

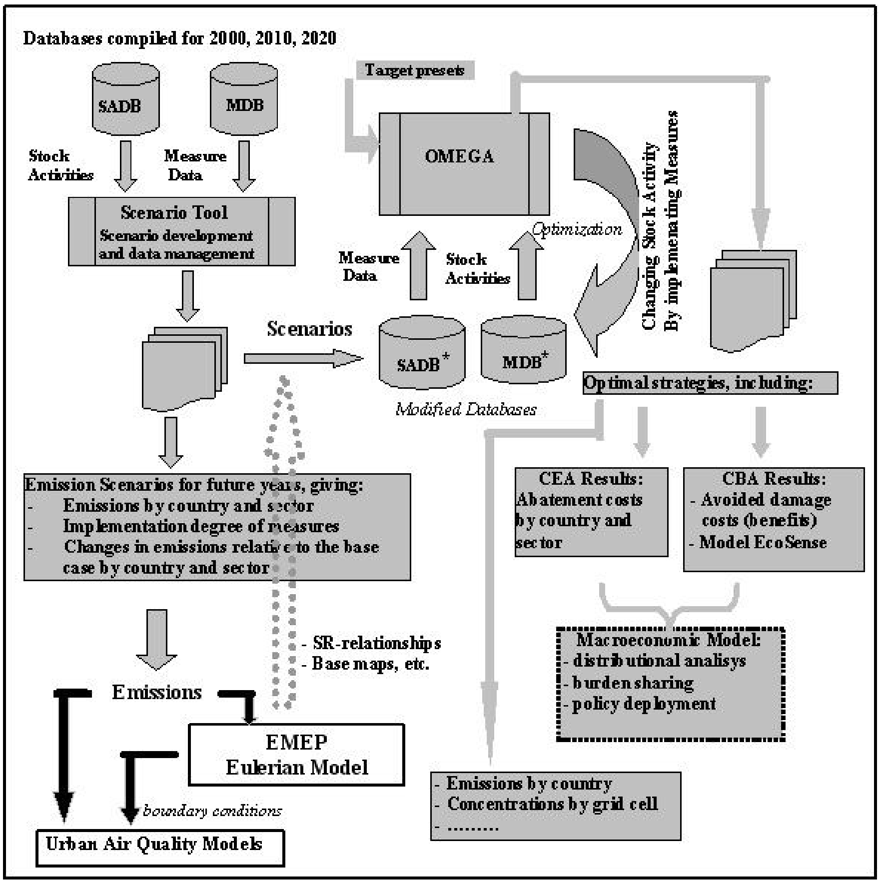

Fig. 2. MERLIN's modeling framework

receptor relationships into the IAM. Using special scenario tools, it is possible to adjust scenarios and create the modified data basis on which the optimization tools are run and thus – to conduct different case studies. The optimisation model developed for this purpose is named OMEGA 2 (Optimisation Model for Environmental Integrated Assessment). With the core optimisation based on genetic algorithms (GAs, or known as Evolutionary Algorithms, EAs), the model can be run in either CEA or CBA mode. The first allows calculations to find least-cost solutions for specified combined air quality (AQ) and greenhouse gases (GHG) targets preset. In the CBA mode a module for monetary evaluation of avoided damage costs is used. It is based on the EcoSense model, following the approach of "Willingness-to-Pay" (WTP). The output of the optimal strategies may include additional results as: different air quality indicators (emissions by country, concentrations by grid cell), exceedance of thresholds (limit values in gridcells), target reduction (in % reduction per pollutant and country) to achieve preset aim, etc. A macroeconomic model is in a process of incorporation in the IAM. On the basis of the costs results obtained, this model is deisgned to provide analyses about the distributional effects between countries, burden sharing and for policy deployment.

The MERLIN's modeling tools allow obtaining of results in different scales – European, regional and urban. In the last case an urban air quality model is developed to be run in close relation with the EMEP model for impact assessment of the overall emission reduction on a local scale.

One major innovation in the MERLIN's framework is the new approach, chosen to incorporate technical and nontechnical abatement measures and costs directly into the optimisation, instead of compiling fixed country and pollutant specific abatement cost-curves outside of the model. For this purpose a new "measure-matrix" approach for modeling of the abatement options is used. Another innovation is the application of generic algorithm in the optimization procedure.

2.2. "Measure-matrix" approach

Basically, during the project MERLIN the same data that would be needed for each IAM to generate abatement costs curves is collected, but it is more detailed in order to improve the reproduction of sector-specific characteristics. This comprises the following main data types:

- data on stock and activities (e.g. number of vehicles and annual mileage);
- data on technical and non-technical measures (e.g. applicability, efficiency, implementation degree, costs);
- "meta-data" (information on relationship between measures).

Stock Activities Database (SADB) and Measures Database (MDB) are compiled for target years 2000, 2010 and 2020. Instead of trying to process and split this data into single abatement cost curves, the optimization model is given full access to the databases allowing to select, apply and evaluate abatement options with a considerable degree of freedom. This permits the inclusion of structural changes due to the implementation of abatement options, for instance increasing the activity of one sector in order to reduce that of another [4]. This "measure-matrix" approach creates a number of additional modelling opportunities, e.g. a possibility to assess single measures, individual sectors or whole countries/regions with only simple presets, as no pre-processing of data is needed. Moreover, it does reflect the real-world characteristics of abatement options to a far greater extent than before, since in most of the cases the costs of abatement options are expressed relative to their application on stock or by activities. In addition to that, abatement options usually address not only one single pollutant, but a portfolio of different pollutants, either reducing, or increasing emissions. This is of particular importance for the assessment of multi-effect problems, because such analyses usually have to achieve conflicting targets. Finally, this approach is not limited to mere technical abatement options, for it can include structural measures and other non-technical abatement options in the same way. Thus, the measure base approach has a number of advantages over the "traditional" ways to conduct cost-effectiveness assessments, which are, among others: transparancy, flexibility and modelling real-world abatement options.

2.3. Optimization algorithm OMEGA

IAMs to date usually apply either linear optimization algorithms [1] or simple iterative approaches which are not suitable for decision of multi-effect problems. The evolutionary (also known as "genetic") algorithms (EA) can be the ideal tool even though they have not been widely applied in the field of air pollution modeling yet. EAs optimize in a way similar to that of the nature, using such concepts as recombination, mutation and fitness for survival to induce a process of evolution towards an optimal solution [2]. The decision to apply EA emerged when it became clear that the problem to be solved was characterised with necessity to combine hundreds of different abatement options. For this particular situation, other approaches that were investigated, for instance global or local random choice, gradient based algorithms or divide and conquer strategies could not offer satisfactory performance.

The optimization algorithm OMEGA 2 (the OMEGA 1 model was developed for the optimization of ozone abatement strategies) as it is applied in the MERLIN project, forms the core of an IAM to conduct cost-effectiveness (CEA) and cost-benefit analysis (CBA) of combined strategies to reduce air pollutant and greenhouse gas emissions simultaneously [4]. The implementation of an evolutionary algorithm to identify optimal bundles of abatement measures is illustrated on Fig. 3.

In principle, the problem to be solved can be formulated as follows: from all possible abatement options (measures), a set of measures has to be identified which fulfils all criteria simultaneously at least costs.

Steps 1 and 2 form the initialisation to start the optimization and enter the loop, where – in our case – abatement options are selected to reduce a variety of emissions to air. In step 3 the resulting changes of concentrations of pollutants are calculated, using the so-called source-receptor matrices (SR-M) [5]. To reduce computational effort in this step, the resolution of the matrices is first reduced and then gradually increased at every generation run, until the finest grid resolution of 50×50 km is reached.

Thus, using the total costs of the abatement measures and the preset thresholds that are still exceeded, the strategies can be evaluated in Step 4. This approach allows different weights for limit values that are not achieved, introducing the so-called "fitness value" which will then be used to discard the worst performing strategies.

Pairs of strategies (parent generation) are selected in Step 5 according to their degree of fitness, that will pass their measures on two newly formed strategies (child generation). In the first step, an *n*-point crossover mutation approach is implemented in the algorithm, as illustrated on Fig. 4 for the case of two-point cross-over, where the parent measures are cut in a number of pieces, which are then recombined to form the offspring.

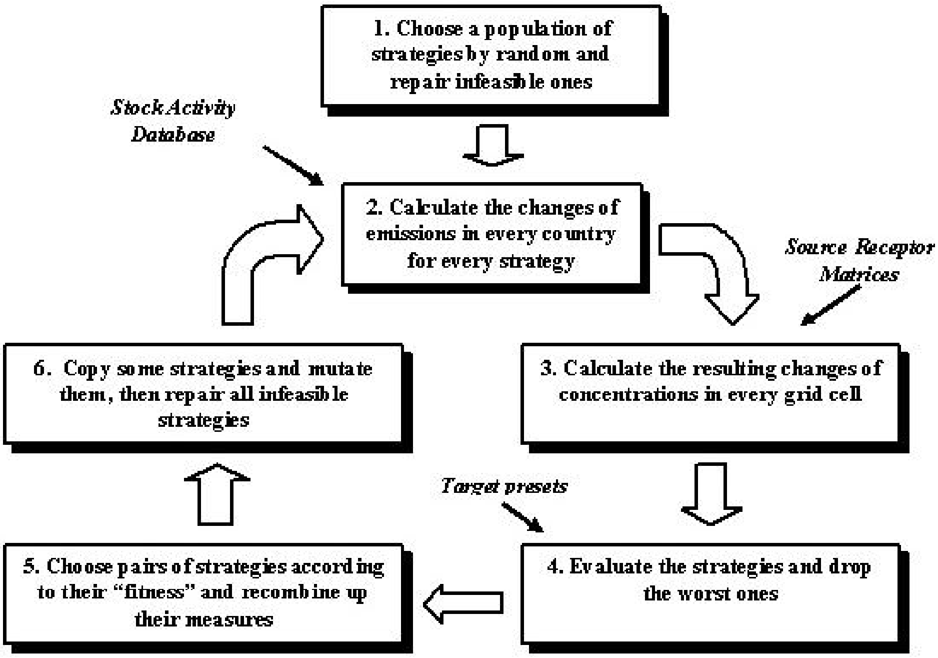

Fig. 3. Implementation of an evolutionary algorithm in IAM

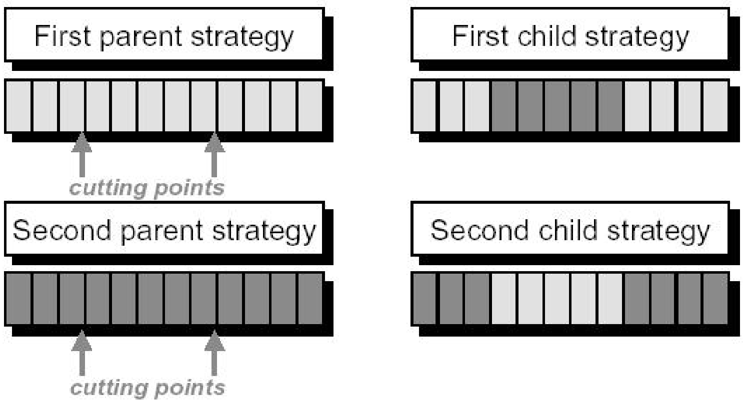

Fig. 4

The position of the measures within the strategies plays an important role as well. If, for instance, two strategies with sufficient fitness are selected in step 5 (Fig. 3), it would be harmful to place measures of the first strategy (which, for instance, focus mainly on reduction of one particular pollutant in one country) at the beginning and those of the second strategy at the end. In this case their offspring (the next generation) would probably consist of one strategy that has not such measures at all and one that has twice as much as needed. This will cause a disbalance in the individual strategies during next generation.

To overcome this, groups of measures are formed that have more or less similar effects and some measures may be members of several groups. This is done automatically, so new measures can easily be added to the measure database. The strategies consist of several sections, and every section can only include measures of one single group. So the mixing up of measures in step 5 will either be done by copying the whole measure group of one parent strategy or by *n*-point-crossover.

Aside from solving the problem above mentioned, the measure groups also allow small variations of the strategies, as follows. Most evolutionary algorithms simulate mutation of the individuals. At Step 6, some strategies are chosen by random, and one or more of their measures will be replaced by other ones, that roughly, but not exactly, have the same effect. Because this is the case for measures of the same group, each one that fits into the same position of the strategy (and thus is a member of the same section), can be chosen. To make sure that the fitness cannot decrease from generation to generation, the chosen strategy shall be duplicated, and only the copy will be allowed to mutate. This combination of a global search method (the crossover of strategies, done in step 5) and a local one (mutation as done in step 6) is often considered to be the key to the power of EAs in optimisation problems.

It should be mentioned that different improvements of the EA-approach was planned to be implemented and tested, for example, use of diversity increasing operators, simulation of SINEs (short interspersed elements), use of oscilating emission reduction targets, etc.

3. Summary and results

It is astonishing that a very little advancement in the fields of IAMs for multi-pollutant multi-effect assessment developments is observed during the last decade. Many IAMs still use for this purpose the single pollutant cost curve approach. At the same time we are witnesses of significant computing power and growing knowledge about causes and effects of air emissions, which imrove the modeling possibilities for assessments closer to the reality. At the same time, as the problems to be addressed become more complex, new approaches need to be taken. On one hand, cross-media approaches need to be established, on the other – full integration of models and tools for macro-economic assessments has to be realized. Due to the finalizing of the project in 2004, the importance of the above targets and the necessity to be achieved, the work is continued at present in other projects. At the same time the work on building a web-accessible version of the MERLIN's approach, in order to use the model system for own calculations, is also continuing.

Despite the fact that some of the aims were not achieved during the project, even the present benefits of the MERLIN's approach are obvious: no allocation of costs to single abatement cost curves are needed. Furthermore, measures are either applied or not, reflecting the choice of options in the reality. As the model selects measures from a database, maximum flexibility is achieved, because new measures can easily be introduced or others removed. Besides, the order in which measures are applied is also taken into account.

Some of the results obtained, concerning combined health and climate scenario are here presented. This scenario aims to achieve simultaneously reduction of ozone precursor emissions, compliance with limit values of Particulate Matter (PM10), as well as the GHG emission targets of the Kyoto Protocol. An additional aim is, by means of reduction of deposition of Nitrogen and acidifying substanses, to achieve

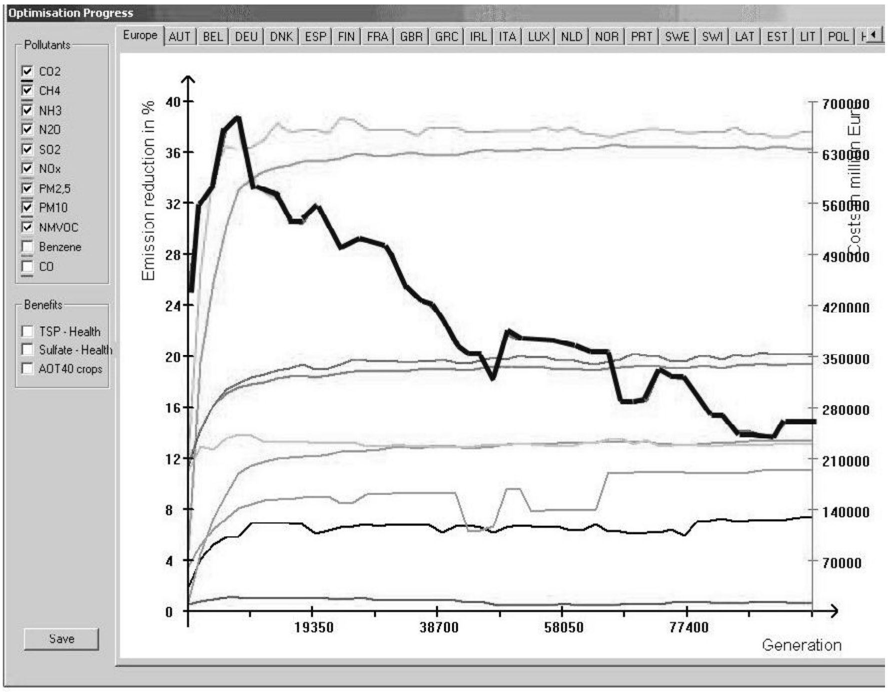

Fig. 5. Optimisation procedure overview

eutrophication and acidification under critical levels in the context of ecosystems protection.

The following initial conditions and target presets are accepted:

- AOT60 2500 ppb.h threshold exceedance allowed;
- PM10 10 mg/m3 limit value;
- PM2.5 10 mg/m3 limit value;
- GHGs Kyoto Emission Targets per country;
- Acidification CCE Critical Levels achievement;
- Eutrophication CCE Critical Levels achievement;
- Meteorology 1997.

Fig. 5 displays the optimization procedure overview. The changes of the abatement costs (solid line) are presented in connection with the emissions reduction, considered for several pollutants and GHGs. As could be seen the total costs can be significantly reduced after an initial peak achieving value of approximately 260 billion Euro in 2010 for the EU25+. The emission reductions is considered focusing on road transport and other mobile sources (NOx, NMVOC, PM10/2.5), industrial production processes (NOx, SO2, PM10/2.5) and power generation (NOx, SO2). The abatement costs are assessed by the respective sectors. The costs due to the road transport, because of the large number of comparatively small sources, are the majour part of the total abatement costs. They include costs for retrofitting the existing vehicles and introducing alternative fuels. Due to the different shares of technologies and industrial production, costs shares for this sector vary across countries. The same refers to the power sector where the distribution of fuels used for electricity generation is the main indicator for the different applicability of measures. Finally, a significant part of NMVOC emissions can be controlled by no or even negative costs due to the recycling of (sometimes expensive) solvents and application of good measures. As a result negative costs are obtained in some countries for this sector, but this depends on the structure of larger activities, connected with significant solvent consumption.

More results about this scenario were presented in the website of the project which is, unfortunately, closed at the moment. But most of them could be seen in [6].

As it was above mentioned after ending MERLIN, the work for improvement of the optimization algorithm and the integrated model as a whole has continued within other projects. Such projects are: ESPREME (Estimation of willingness-to-pay to reduce risk of exposure to heavy metals and cost-benefit analysis for reducing heavy occurrence in Europe **http://espreme.ier.uni-stuttgart.de/**); DROPS (Development of macro and sectorial economic models to evaluate the role of public health externalities on society – **http://www.nilu.no/DROPS/**); TFEIP (Task force on emission inventories and projection – **http://tfeip-secretariat.org/unece.htm**). More information about the projects, the results obtained and the pulications could be found in the respective websites.

References

1. Amann et al. Final Report on Work Done under EU Acidification and Ozone Strategy. International Institute for Applied System Analysis (IIASA), Luxenburg, Austria, 1999.
2. Fogel, D. B. An Introduction to Simulated Evolutionary Optimization. – In: IEEE Trans. on Neural Networks: Special Issue on Evolutionary Computation, Vol. **5**, 1994, No 1, 3-14.
3. Reis, S., S. Nitter, R. Friedrich. On the Use of Abatement Cost Curves in Integrated Assessment Modeling . – In: Proc. of the 16th Conf. "Informatics for Environmental Protection" (W. Pillmann, K. Tochtermann, Eds.), Vienna, Austria, International Society for Environmental Protection. ISBN 3-9500036-8-1. Vienna, 2002, 689-696.
4. Reis, S., S. Nitter, R. Friedrich. Application of Genetic Algorithms for the Optimization of Multi-Pollutant Multi-Effect Problems. – In: Proc. of iEMSs Conf., Osnabrueck, 2004. Available on CD-ROM and as a pdf file at the website **http://www.iemss.org/iemss2004/**.
5. Simpson, D., K. Olendrzynski, A. Semb, E. Steren, S. Unger. Photochemical Oxidant Modeling in Europe: Multi-Annual Modeling and Source-Receptor Relationships. EMEP/MSC-W Report 3/97, 1997, 1-52. Available as a file EMEP_1997_R3.pdf at the website **http://www.emep.int/mscw/mscw_publications.html.**
6. Todorov, T. An Integrated Approach for European Air Pollution Assessment. BALWOIS 2006 Conf., Ohrid, FYR of Macedonia, Available as a pdf file on CD-ROM and at **http://balwois.mpl.ird.fr/balwois/administration/full_paper/ffp-849.pdf.**