The Emission Inventory System for Upper Austria: The Role of Environmental Information Systems in Translating Complex Information to a User's Requirements

Wilfried Winiwarter and Gerald Schimak

ARC Seibersdorf research, A-2444 Seibersdorf, Austria. E-mail: wilfried.winiwarter@arcs.ac.at

Abstract: Advances in environmental sciences increase the difficulty in creating products that can be readily used by non-experts. In this paper we demonstrate how a carefully designed environmental system is able to provide solutions. While complex transformations are kept in the system background, predefined expert choices give a user great flexibility in selecting what is required for the specific applications. In the given case study, emissions of atmospheric pollutants in the province of Upper Austria can not only be calculated for a multitude of options, but a scenario tool also allows for deep modifications of the models, if required. The example demonstrates how environmental experts and computer science experts have to work hand-in-hand to translate model treatment of environmental processes into a user-friendly environment. The overall system is also characterized in its theoretical framework. Seen as a deterministic model, an increasing amount of data input and better understanding of the underlying processes will allow a more realistic simulation of the reality. Without a full validation, however, just increasing the model size will not improve performance. Instead, an expert system will be built, which is overdetermined with respect to input quality, but contains the best available expert judgement on the processes described. Such an expert system should not be expected to possess any predictive qualities outside of the range of the test data. Consequently data reduction has to take place both in terms of model complexity and in terms of the required input. This kind of data reduction requires implicit expert knowledge, model reductions are the essence of any explicit process description.

Keywords: emission, air pollutant, expert system, geographical information system, modeling limitation

1. INTRODUCTION

Emission inventories are fundamental requisites to assess the human influence to the atmosphere. Consequently emission inventories find their application in any attempt to understand anthropogenic effects of air pollution and atmospheric chemistry, and in all efforts to reduce this environmental problem. While the former is primarily a task of scientists, the latter lies in the principle interest of policy makers.

A number of activities are in place to provide information on atmospheric emissions. The GENEMIS program has been devised as a scientific effort to provide information required to atmospheric scientists. But also the political approach, which is highly valued as it provides the ground for international agreements on emission reductions, strives for accurate information. These international agreements, namely the Convention on Long Range Transport on Air Pollutants (CLRTAP) agreed within the UNECE, and the UN Framework Convention on Climate Change (UNFCCC) safeguarding the Kyoto protocol on greenhouse gases are the most important for Europe. These conventions and the protocols oblige the authorities of those countries which are parties to the conventions, to regularly submit emission information at a standardized quality and format. In order to facilitate the compilation of such information, guidebooks have been compiled, most notably the EMEP/CORINAIR Atmospheric Emission Inventory Guidebook [UNECE, 2001] and the IPCC guidelines [IPCC, 1996].

Compiling an emission inventory is a tedious task. A multitude of input parameters have to be collected [Power and Baldasano, 1998]. Depending on availability at a specific investigation area, data are derived from measurements, from literature information, statistical data and specific surveys. Collection of input data needs to be performed in a manner that satisfies the requirements. Stringent quality criteria have been introduced in inventories created as a consequence of political agreements: Within greenhouse gas emission inventories submitted by countries to the UNFCCC, quality criteria specifically included are accuracy, completeness, consistency and comparability. Such requirements and the independent review of the resulting inventory, as is the practice within UNFCCC, calls for a systematic approach to collect and calculate emission data.

In addition to their reporting requirements, authorities also need to be able to perform environmental management using this information. For any emission relevant decision, starting from permits for industrial installations to the planning of road networks or city planning, the authority wants to know about the present local situation, possibly also differentiated by the source group and identifying the main polluter. While this task is very different to the reporting obligations described above, much of the input needed is identical for both. The difference is that authorities subcontract work that leads to a very defined product as needed to international reporting, but it is virtually impossible to outsource all the individual queries needed for each of the environmentally relevant decisions, especially as much of the information required is of confident nature.

The task of the work described in this paper therefore was to create a system which is able to use the experts' input to compile an emission inventory, and delivers the results in an easily accessible and usable form.

2. SOME THOUGHTS ON MODEL THEORY AND LIMITATIONS OF THE APPROACH PRESENTED

Models simulate aspects of real systems. Due to today's high computing power, computer models used in environmental (and other) science have tended to become very explicit and detailed. There are cases where the quality of input data is sufficiently high to warrant that effort. This is, the quality of output is fully reflected by the available input.

But beyond a certain degree of input detail, model validation will not be able to confirm any better results. And there is the case of models which per se escape any validation effort. Such models may be perceived as sort of expert systems, where all the best information of experts flow into the algorithms as well as into the respective parameters and assumptions.

The exact formulation of system interactions is only second priority in this matter, an explicit formulation of equations is in that sense as good as a genetic algorithm approach or as cellular automata. In any case it will be the experts choice to decide on possible and allowable simplifications. At this point there is no need to add more information or structure to the model, beyond the point of which it can be verified. To avoid unnecessary ballast is part of the art of modeling. Computing power is not the problem any more – it is rather a matter of limiting the data input, data which may be tedious to obtain and of unclear quality, as possibilities for error checks also decrease with increasing data amount.

Adding information to an expert system can always be justified. It makes sense to improve processes, just to be sure the best available information is included, even if there is no immediate response on the output side. Nevertheless it needs to be spoken out clearly what such expert systems can do: they resemble our best understanding of how we believe a system is operating. They have no general claim to resemble reality. In contrast to other models used in the physical sciences, such expert systems also do not have any predictive qualities [Jeffries, 1992], or at least their predictive quality is limited by the extent to which the respective models undergo verification.

Such models simulating natural systems need to be assembled by two types of experts: those that understand the natural systems, and those that are able to transform the concept into computing algorithms. It is both the natural scientist, who suggests the simplification to be made, and the computer scientist, who provides the framework and offers the translation, who have to cooperate to provide acceptable results.

3. PRACTICAL APPROACH

3. 1 An Emission Inventory for Upper Austrian

Upper Austria is one of Austria's nine provinces, economically characterized by heavy industry in and near the capital Linz. It comprises more than 1.3 mio inhabitants in an area of about 12000 km². After considerable emission reductions by the aforementioned industry, any further improvement requires a detailed planning. Thus the provincial government commissioned an emission inventory for the area of the province, covering all potential sources of atmospheric emissions for the pollutants

SO_2, NO_x, NMVOC (non-methane volatile organic compounds), CO and PM (particulate matter), plus the climate gas CO_2. The method of inventory compilation followed the Austrian Standard for atmospheric emission inventories [ON, 2000]. It consisted of the results of an extensive industry survey as well as the collecting of a multitude of statistical or specific emission relevant information.

The resulting study [Winiwarter et al., 1999] not only covers the results of the inventory in terms of annual emissions of the compounds investigated by source group and geographical area, but it also describes the unique approach taken: the combination of all relevant information into a fully accessible database, which allows to retrieve information in a user-friendly way with a multitude on individual inquiries already implemented and open to even more. The basic concept of treating the computational challenges has been described previously by Schimak and Winiwarter [1999].

3. 2 The Three-Layer approach

The emission inventory system was designed as an MS Access® database. In addition to the input tables and the output, an intermediate layer was introduced, which proved advantageous both in computational terms as well as for the practical application. This layer was implemented as an extra set of tables in the database - tables describing the annual emissions of each smallest subsector for the smallest geographical unit used. As emission sources are treated in three different geographical structures (point sources, line sources, area sources), for each of these structures a separate table was introduced.

Thus the modeling system consists of three layers and consequently two sets of models (algorithms) to join them (Fig. 1). The main reason for this split of algorithms is that the emissions need to be calculated from input data very infrequently, and this calculation requires a considerable amount of computing time. The visualization, on the other hand, is the main application of the model and performed fairly frequently, but requires only little computing power. But the split also allows a separation of the model into an expert's sphere (the emission calculation) and a user's sphere (the evaluation).

3. 3 The Emission Calculation Algorithms

As a consequence of the diversity of available input data, also a multitude of different schemes and algorithms were derived to calculate emissions. The most basic approaches were adding up results of emission measurements vs. applying literature emission factors to statistical information on the activity of a certain process.

Separate calculations for distinctive geographical or sectoral units required either keeping the relevant measured quantities separate, or to artificially segregate them. Such a segregation procedure, called disaggregation, applied surrogate statistics (e.g.: population numbers for the spatial distribution of activities considered to be performed to a similar extent by people) to a sectoral or spatial total. The procedure as such has been described in detail, e.g. by Loibl et al. [1993] and by Power and Baldasano [1998].

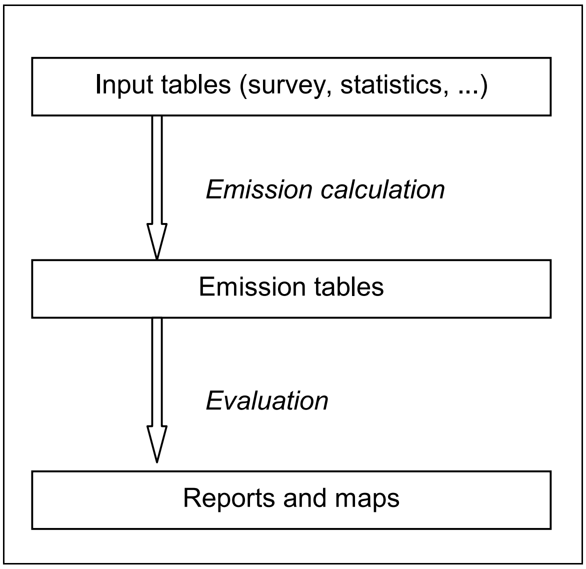

Figure 1. The three-layer model for calculating atmospheric emissions.

The resulting emissions are stored in the emission tables (Tab. 1), separately for point sources (emissions which are assumed to derive from a specific point like a stack), line sources (emissions along a road, given by road segment) and area sources (other emissions which are not further attributed than to the administrative area they are emitted from). The tables contain the emissions of any of the pollutants given by the respective geographical unit, and by their source sector. Such source sectors are basically an economic account of different sources, but they also may describe the emission process as such, e.g. they also separate different vehicle categories in the sector traffic.

Table 1. Structure of the area emissions table.

Field descriptor	*Field type*	*Key*
Area code	Numeric	Y
SNAP (process code)	Numeric	Y
SNAP-detail	Numeric	Y
Process detail	Alphanumeric	Y
NACE (economic code)	Alphanumeric	Y
SO2 (emission)	Numeric	-
NOx (emission)	Numeric	-
NMVOC (emission)	Numeric	-
CO (emission)	Numeric	-
CO2 (emission)	Numeric	-
PM (emission)	Numeric	-

3. 4 The Evaluation Algorithms

While the possibilities to extract information from the emission tables is principally not limited, a few specific queries have been implemented to serve as examples for practical applications. The queries result in emission data output in the form of reports or as thematic maps, using the geographic information system ArcView® (ESRI Inc., Redlands, CA).

Upon selection of specific criteria - base year, pollutant, administrative district, source sector and some source sector combinations - the predefined queries are executed and the resulting maps or reports are available for further manipulation steps. As these queries have been selected according to the users' request, they cover a large part of the needs for routine data extraction. Due to the well-defined table structure of the emission tables, further evaluation algorithms can be added in a straightforward manner.

4. RESULTS AND DISCUSSION

A typical output ready for use in public negotiations or in reports is shown in Fig. 2. In addition to maps, also pre-defined tables are available which list the emissions of each compound by geographic unit (not shown).

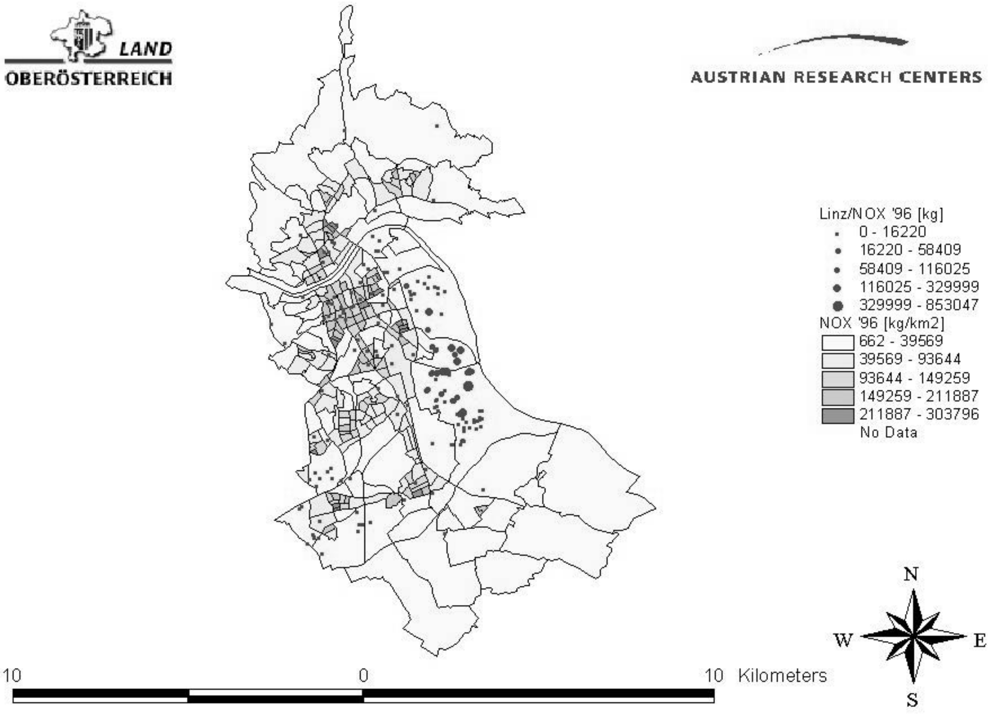

Figure 2. Emission map for all area sources and point sources of the district of Linz, Upper Austria.

These examples represent only a fraction of the possible options. In a similar way, emissions differentiated by source type or by emission process can be displayed, with separate treatment for point, line and area sources.

The details of display options for the results must not be mistaken for the accuracy of the results, however. The only way to assess how realistic the results are is a comparison to independently derived data. Sturm et al. [1999] have compiled possibilities to perform such validations. An intercomparison exercise has been performed, using results from an all-Austrian emission inventory [Ritter et al., 1999] that had been disaggregated to the level of provinces. The result - not available for PM, though - proves a good agreement to the totals, but much weaker agreement for the individual source sectors (Fig. 3).

While many of the respective differences may be assessed individually, and have been explained to some extent, for a majority of the differences sufficient reason can not be given. Part of the discrepancy in NMVOC derives from a different accounting system, while the same nomenclature is used, for agricultural vs. natural sources. An other part, both for NMVOC and NO_x, is due to different aggregation factors for stoves burning firewood. Different base periods were used for industry sources. All of this has been documented by Winiwarter et al. [2001]. Furthermore, there is no possibility to validate the even much finer source differentiation available in the present inventory, or even more so the very detailed spatial resolution, even if some attempts have been made also in this direction [Winiwarter et al., 2000].

The theoretical outline given above in section 2 documents the merits of such a model, which can be validated only in part. The model needs to be seen as an expert system in such a case. This is an information system containing as much of the expert knowledge available, and making it more widely accessible. While such a system may not be able to fully reflect the actual situation, at least it provides the best information that is available. Further efforts in validation may help to improve knowledge on the physical systems and thus increasing expertise that can again be fed into the information system.

While such data quality may not fully suffice for modeling atmospheric processes, it still is good enough to support environmental decision making. The scientific background for decision making is as good as information can be made available, as assessed by the validation and expert judgement.

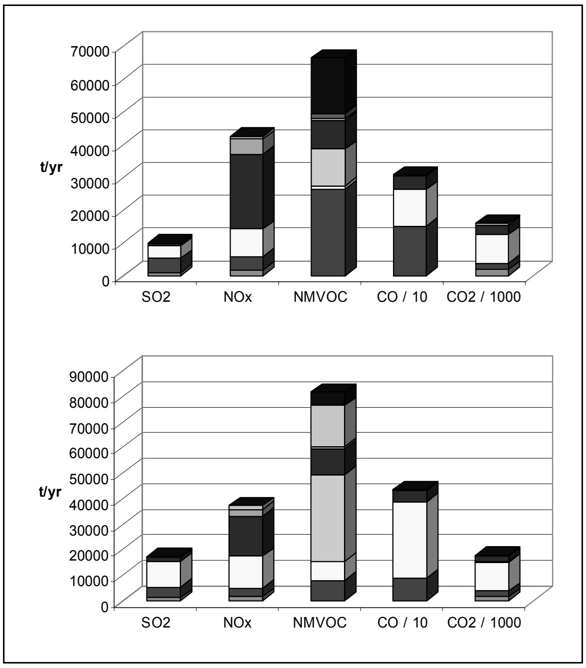

Figure 3. Comparison of this emission inventory (upper panel) with a centrally derived independent inventory (lower panel). The different colors denote the available source sectors.

Consequently, also an option for scenario making is included. This option allows for changes in the input parameters, affecting the information system quite deeply. Such interventions are difficult to make, and consequently are limited to experts. This is not a disadvantage. A careful interpretation is required of results of such scenario analyses, as the emission inventory system has not undergone a rigorous validation covering also this aspect. The fact that expertise is required to access this option consequently also limits the interpretation to experts and makes sure that results are seen as system outputs and can not be taken for predictions.

5. CONCLUSIONS

Citizens have a right to know about the quality of the air that they breath. Such kind of information can only be compiled centrally by air quality authorities. A transparent emission information system allows to make such information available.

The emission inventory for Upper Austria has been created in a way to provide the most advanced procedures for emission calculation, and at the same time keep these procedures in the background. The interfaces available to the user are simple and straightforward, and the user can access emission data without having to know about all complexity involved.

Critical for the development of the three layer model which allows the strict separation between a user's sphere and the experts' sphere was a very detailed interaction of the computer scientists and the emission experts. During each stage of the project, all attempts were made to transform as much as possible the emission relevant knowledge into the information system's procedures. Neither can such a model be driven by its mathematics (and computer algorithms) alone, nor can the emission expert construct a system that is at the same time also helpful to the administrative user.

It is no contradiction that the experts' sphere is still openly accessible. This even increases transparency and reproducibility of emission calculations. The access is safeguarded by the detailed knowledge required to understand the database. In this way, the system adapts itself upon a user's competence.

6. ACKNOWLEDGEMENTS

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