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emikat.at – Management and Visualization of Spatially Resolved Emission Inventories and Emission Scenarios

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Abstract

Emission inventories require the management, documentation and interrelation of large amount of heterogeneous data in a user-controlled logic. emikat.at is a system that supports those who establish emission inventories and work with it.

emikat.at consists of a data administration server and a user interface residing on the users' PC's (client). At the server database all data is administered specifically for different clients and different versions. Access is limited to authorized clients and their users. Through the user interface, users have the possibility to add, edit and delete data as wells as to define alternate scenarios and to calculate model results. emikat.at derives emissions for the smallest available administrative units, i.e. „census tracts". In each census tract, emissions are calculated according to the specific properties of emission sources, organized according to business sectors (NACE-system), emission source categories (SNAP-system), as well as according to input materials, fuel types and transformation processes. Emissions from line sources (road traffic) are directly associated to the major roads of a census tract. Emissions can also be calculated on the basis of a 100x100 m raster grid; in that case, land use within a census tract is considered for the spatial allocation of emissions. Results that have a defined spatial reference (such as census tracts, communities, counties, raster cells) can also be visualized as maps.

The system was applied to calculate the emissions for the reference year 2003 for the city of Vienna along with two „what-if"-scenarios of this reference year. This paper includes a few illustrative results from the Vienna case study.

1. Background

Emission inventories are essential components of air pollution management, as they provide information about the significance of emission sources and their contribution to overall air pollution. Emission inventories are based on a survey of emission-generating activities and activity-relevant emission factors in a given spatial domain. The temporal resolution is usually a given reference year. The methodology of establishing emission inventories is well documented in international guidelines (e.g. US EPA 1985-1993; EEA 2004).

Only few emission generating activities can be directly assessed: examples for that would be the fuel consumption of individually known large power stations and industrial plants. For most other air pollution sources (such as motor vehicles and residential heating) it is necessary to establish data models to calculate the contribution of the respective source groups by using surrogate data. For instance, emissions from motor vehicles may be estimated by using information about the overall number of vehicles in use and their fuel system (gasoline, diesel), their technical features and typical emission control systems, plus the driving characteristics (mileage, driving modes on different road types) etc.

In order to calculate the emission of pollutants, activity-specific emission factors (such as the amount of air pollutant released by a unit of activity, e.g. grams of CO per km driven) are combined with emission-generating activities. This sounds simple but is a complex process. Often it is necessary to use different calculation methods in order to get reliable results and to reduce uncertainties. Thus – while the results of

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emission inventories consist of relatively simple data tables – the production of these require complex data models.

The complexity is even more pronounced when it comes to the establishment of emission scenarios. Scenarios reflect assumptions about „what if" certain emission-generating activities are being changed. Such scenarios are useful for the establishment of air pollution management plans. It is most important that all underlying assumptions of scenarios – emission generating activities, emission factors, or calculation models – are fully documented; otherwise it would not be possible to relate differences in emissions to changes of input data.

2. The emikat.at data system

emikat.at is a data system for managing emission-relevant data (i.e. emission-generating activities, emission factors, supporting information). All data, data interconnections and data changes are documented in the form of specific versions. Details of the system have been published recently (Orthofer et al. 2005). emikat.at allows to

- import, store and document base emission-relevant data and data linkage models
- calculate emissions according to different models
- summarize results according to user-defined requirements
- visualize results as maps.

emikat.at was established in close cooperation with the Environmental Protection Department of the City of Vienna, which has defined use cases and user requirements of the system. Theoretical considerations about the requirements for an emission inventory data management tool were presented at previously at EnviroInfo Cottbus (Humer et al. 2003).

2.1 Concept

2.1.1 Architecture

emikat.at consists of a central data server and an end-user application client. The data server is used for centralized data management and backup; it is based on Oracle 9i. The purpose of the client is to allow the users – depending on their access rights – to upload and download data, to change data sets, to establish or change calculation models, and to summarize and retrieve results. The client is a Java application. Whenever the client is started it checks the user rights and privileges and provides access to the server. If an updated version of the client is available on the server, the client is updated automatically.

2.1.2 Features

emikat.at allows to organize, document and to logically interconnect large and heterogeneous data sets in a user-definable documented logic. All data changes and calculations are documented. Thus it is possible to relate all results to input data and calculation models.

2.1.2.1 Conformity to national and international standards

The emission data system is based on international and national standards with respect to input data accuracy, calculation methods and categorization of results.

2.1.2.2 Version-specific data management

The system allows managing different versions of data sets. Such different versions of certain datasets can be combined to reflect different scenarios.

2.1.2.3 High spatial resolution

The spatial resolution of the system depends on the requirements of the users. For the requirements of the City of Vienna, the spatial resolution refers to the census tracts of the Austrian Statistical Service which comprise units of about 1000 inhabitants. In Vienna with an overall area of about 41 500 ha, there are about 1 400 census tracts with a size between about 1 ha and 2 000 ha. To account for heterogeneous emission densities in the larger census tracts in the outskirts of the city, the system includes an ex-post spatial disaggregation in a 100 x 100 m raster grid. This grid system allows to allocate „uniform emission sums“ within a census tract into their emission-relevant raster cells based on the respective land use: e.g. emission from industry would be allocated only to raster cells that relate to industrial land-use, emissions from domestic sources only to those raster cells that relate to residential areas, etc.

2.1.2.4 Different types of emissions

The system handles three different types of emission sources: point sources, line sources, and area sources.

Point sources relate to known locations. They are spatially defined through their respective long/lat coordinates that are automatically derived from their addresses. Emissions can be easily related to the relevant census tract or to the relevant 100 m raster cell.

Line sources relate to activities along roads. In Vienna, about 1 000 km of roads have been defined as lines. Line emissions are spatially allocated to the census tracts in which they occur. Line emissions are important for emissions from motor vehicle exhaust and for particles emissions caused by motor vehicles movement. Emissions from line sources are allocated to the respective census tracts according to the relative length of a line in a census tract and to the respective 100 m raster cells.

Area sources relate to sources whose locations are not specifically known. This comprises the majority of sources, including motor vehicle traffic on secondary roads, residential heating, and small industry. Area emissions are typically calculated using surrogate statistical information, either for each census tract, or for the overall area. In the latter case emissions are spatially disaggregated to emission-relevant areas using land-use distribution function. For instance, emissions caused by utilizing nitrogen fertilizers in agriculture may be calculated from overall usage statistics for the total of Vienna, but the spatially disaggregated to relevant census tracts using land use data. Within the census tracts, emissions are allocated to the raster cells according to the respective land use (e.g. agricultural, residential, industrial, traffic, etc.).

2.1.2.5 Variable temporal resolution

According to international standards, temporal resolution of emission inventories is a full year. The users define a reference year and the system will look through the data base for all data that refers to this reference year or – in case such information is missing – for data in the year before, or even earlier than that. This is very useful as often data about emission-relevant activities are not available for every single year. For instance, census data for households might be available only every ten year, while reliable data about the average car fleet can be expected every single year, and fuel consumption in power plants might be published even every month. As a result the emikat.at emission calculation for the reference year reflects an inventory that is based on “all information available until the reference year“. It is more

important to have a full emission inventory that reflects the situation during a period of years rather than to have an inventory for a specific year that lacks certain activity groups.

Within a base year, the system can be used to estimate short-time temporal emissions intervals through applying temporal allocation models. Such short-time emissions may be calculated for months, weeks, days, or even hours.

2.2 Client

When started, the client checks the user for access rights and provides access to the data. The emikat.at client uses a Windows-type interface that is familiar to most users (Figure 1).

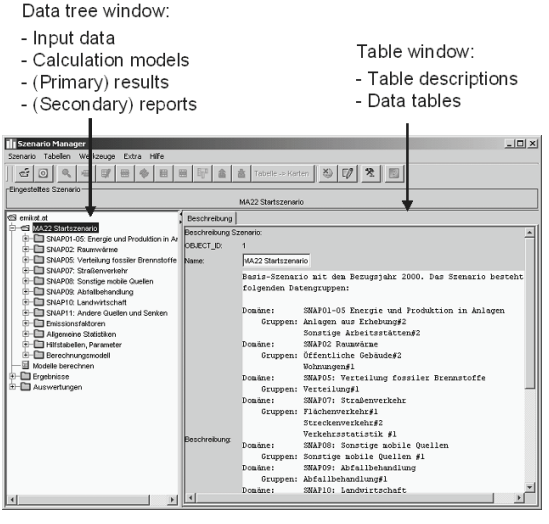

Fig. 1: The emikat.at user interface (start screen)

On the left hand side the user has the tree window, which provides a hierarchic structured overview of all data. These include (a) scenario- and version-specific input data, data linkage/calculation models, (b) primary and secondary results and (c) user-specific reports.

- Input data are organized according to the international standard SNAP-system. Furthermore there are supporting data such as nomenclature systems, inventory guidelines and emission factors. The data tables are organized into about 10 logical „data groups“ (such as a group for residential heating, or another one for motor vehicle traffic on major roads) that have unique version ID's. A set of different versions of „data groups“ makes up a „scenario“. This is an efficient way of managing several scenarios that might differ only in few aspects from each other (for example: one scenario might refer to simply changing the proportion of gasoline and diesel cars; such a change would require a small change in only one of the data tables, which leads to a new "version" of the respective data group, while all other data groups remain unchanged). Data linkage models are also part of the input data set. These models are essentially SQL-statements that translate the logical framework of linking input data table elements. Data models are also a version-specific group; thus a change of the calculation system results in a different scenario, too.
- Primary results are the result of the detailed emission calculation that is done separately for point sources, line sources, and area sources. They contain three data tables that give a detailed summary of all calculation results. The layout of the three tables refer specifically to the features of the type of sources; however, the results would typically be give as emissions per spatial unit (usually census tracts, in the case of line sources also the individual roads), per source category (in the case of point sources this would also refer to individual sources), per economic activity type (NACE), per fuel type used, per pollutant, and per calculation model. All result tables are linked to relevant information of the input tables. Thus it is possible that for any particular result data set the respective input data set can be looked up. All three primary results can be combined in a secondary „total emission“ data table. This is an aggregated harmonized cross-table with emissions per spatial unit, per source category and per pollutant.
- Reports are configurable modules that extract user-specific short reports from primary and secondary results by using SQL-like syntax. Such reports can be data tables that relate to spatial units (such as emissions per district per pollutant) that can be visualized as maps, or they may be complex data tables that extract other information (e.g. a list of major emission sources in a district that exceed a certain threshold and might have failed to provide their last year's emission statement).

3. Emission modelling for the City of Vienna

The emikat.at system was applied to calculate the emission of SO_2, NO_x, CO, NMVOC, CO_2, TSP und PM10 in the City of Vienna for the reference year 2003. As mentioned above, the term „reference year“ means that the emission calculation refers to all information that was available by 2003. As much of the information used for the inventory was from 2000-2003 the results reflect the average situation in one year during that period.

Three different emission cases were considered. In addition to the reference case we have added two demonstration „what if“ scenarios, namely (a) a reduced usage of Diesel cars ("Minus Diesel") and (b) a phase-out of liquid and solid fuels for residential heating in the more densely populated parts of the city ("Cleaner Heating").

3.1 Data

3.1.1 Emission-generating activities

Input data were taken from routine statistics, traffic models and surveys. Land use was available for about 40 different categories. All data were organized according to the standard international air emission reporting system of the European Environment Agency (SNAP-system).

3.1.2 Emission factors

Emission factors were collected from the available international standard recommendations (e.g. EEA 2004), from national compilations (Stanzel et al. 1995), from the AT-CH-DE handbook of emission factors for road traffic (Keller 2004) and from numerous other sources. The emission factor data base contains about 3 000 emission factors for the 7 pollutants and numerous different processes and units.

3.1.3 Data linkage models

The biggest challenge for the emission calculation proved to be the multiple linking of heterogeneous data within a documented and consistent calculation scheme. Base data were available in multiple – at times incomparable – units. Thus calculation had to consider a distinct procedural logic, such as calculation cascades:

FOR source category_#1
IF there is information about activity indicator_#1 and _#2
THEN calculate emissions by linking indicator_#1 with indicator_#2
ELSE
IF there is information about indicator_#1 and _#3
THEN calculate emissions by indicator_#1 with indicator_#3
but in that case exclude the emissions calculated already before
ELSE
IF...
THEN .....

About 50 different data linkage models were used to calculate all emissions. Most data models are used to calculate emissions "bottom-up" for each census tract. In case data models calculate emissions for the overall city of Vienna (e.g. NO_x emissions from lightning) they include a method for an ex-post allocation to the respective census tracts. Calculation takes several hours and is typically run as an overnight batch process.

3.2 Results

Results were calculated separately for point sources (about 4 000 data sets), line sources (about 1.5 million data sets), and area sources (about 160 000 data sets), differentiated for spatial relevance, emission category, economic sectors, and for „causes" of emissions (e.g. fuel use). These primary results were combined into a secondary uniform „total emission" data table that summarizes results for census tracts, source category (SNAP-system), economic sector (NACE-system). In this table pollutants are included as a cross-table; nevertheless the table still contains about 80 000 data sets.

3.3 Reports

3.3.1 Tables

Primary and secondary results are combined and summarized into tables that satisfy typical use-cases. Such reports are generated through SQL-like scripts. Examples for such reports are tables that aggregate emissions for the 23 municipal districts, or that summarize results for subsets of selected pollution sectors (e.g. households, infrastructure, traffic etc.). Currently emikat.at uses about 60 predefined report types, but these may be extended ad libidum depending on the special preferences/needs of the user.

3.3.2 Maps

Report tables that relate to a defined spatial unit can be visualized as maps. Such spatial units may be the 23 municipal districts, the 1 364 census tracts or – together with a special ex post disaggregation model – a 100 x 100 m raster grid system with about 40 000 cells.

Map results are particularly useful to translate long and difficult-to-understand tables into images that show the spatial dimension of the emissions. Such visualization provides a useful basis for targeted abatement measures. However, users must keep in mind that the „power of mapping" also requires great care regarding the definition of appropriate map features (e.g. using spatial densities of emissions rather than absolute amounts) and the selection of class boundaries and colours (for more details of the challenges of mapping see Monmonier 1996). Default mapping refers to predefined administrative units, such as municipal districts or census tracts. In order to account for the heterogeneous spatial characteristics in large census tracts, an ex-post spatial disaggregation of emissions into a 100 x 100 m raster grid was developed: though this, the emissions within one census tract are allocated to raster cells in this tract according to the land use that relates to an emission source (e.g. emissions from road traffic are allocated to raster cells in which land use pertains to road traffic, emissions from households are allocated to raster cells that pertain to residential areas, etc.).

3.3.3 Scenario comparison

In emikat.at, "scenarios" are results from different versions of the data input tables. Thus all results tables as well refer to the respective scenarios. In the emikat.at system any two different scenarios can be selected and the respective predefined reports can be are be displayed as comparison data tables. For reports that relate to defined spatial units differences can be visualized as difference-maps. This feature is very useful to show the spatial dimension of policy scenarios.

3.4 Example results: PM10 emissions in Vienna

The following paragraphs describe the results of the Vienna emission inventory using PM10 (airborne particulate matter with an aerodynamic diameter <10 µm) as an example pollutant. In the reference case total PM10 emissions are around 1 200 tons/year. More than 60% of the emissions come from road traffic, about 15% from large point sources (infrastructure and industry), 10% from small business, and 5% from households. Within the traffic sector, emissions come about equally from motor exhaust (mostly from Diesel engines) and from diffuse particles that are dispersed along roads (road dust, brake & tire wear, re-suspension). The average emission density is about 29 kg/ha; emission densities exceed 100 kg/ha in 5% of the Vienna administrative area with about 15% of the population, and exceed 150 kg/ha in 2% of the area with about 5% of the population, mostly in the core city.

The changes in the two "what-if" scenarios are documented in Table 1. This comparison demonstrates the power of the emikat.at system: in each of these scenarios only some small simple "what if" changes were made in one of the many data input tables, yet the results allow a preliminary assessment of the impacts of mitigation strategies. The phase-out of current technology Diesel cars (scenario case a) reduces the emissions by -15%, while the phase-out of liquid and solid fuels in the densely populated parts of the city reduces emissions by only -10% (scenario case b). However, the spatial effects of the two strategies is completely different, particularly with respect to the population living in the areas with high emission densities: scenario case (b) that is less effective in terms of overall emission reduction brings down the number of people that live in areas with emission densities >100 kg/ha by -50% while the overall more effective scenario case (a) can reduce this number by only -40%. If only the size of areas is considered, the effectiveness of strategies is again different: scenario case (a) may reduce the size of areas with emission densities >100 kg/ha by -40% but scenario case (b) by only -25%.

	Reference case	**„Minus Diesel" Scenario case (a)**	**„Cleaner Heating" Scenario case (b)**
Emissions (t)	1 200	-15 %	-10 %
Emission density >100 kg/ha			
Population (1000)	250	-40 %	-50 %
Area (ha)	2 100	-40 %	-25 %

Table 1:
Example results from scenario comparison (numbers rounded to reflect uncertainties)

The spatial distribution of emissions in the reference case mirrors the significance of road traffic. emikat.at allows visualizing the results as maps for municipal districts, for census tracts, and for a 100 x 100 m raster grid. While the maps for the 23 municipal districts show that nothing more than that emission densities indeed are higher in the inner city than in the outskirts (Figure 2), the maps for the about 1 400 census tracts reflect the high emission densities in those census tracts that are close to major through roads (Figure 3). As could be expected, the visualization of results in the 100 x 100 m grid reveals that the highest emission densities indeed are along the major road network (Figure 4).

4. Conclusion

emikat.at is a tool that allows the management of data that are relevant to estimate air pollutant emissions from heterogeneous sources. Of particular usefulness is the option that all data are stored in different versions and all changes to the data sets are documented. This feature allows to establishing emission scenarios, which could relate to different reference years or to different „what if"-assumptions. The possibility of displaying results as maps is a powerful tool to visualize results and to identify spatial hot sports of emissions.

The primary applicability of the emikat.at-system is for air pollution control at regional authorities, yet we foresee that the underlying method may be applied for other environmental data assessment tasks where heterogeneous data need to be combined, linked and assessed with data models. For example, emikat.at could also be used as a starting point to develop a spatially resolved water information system.

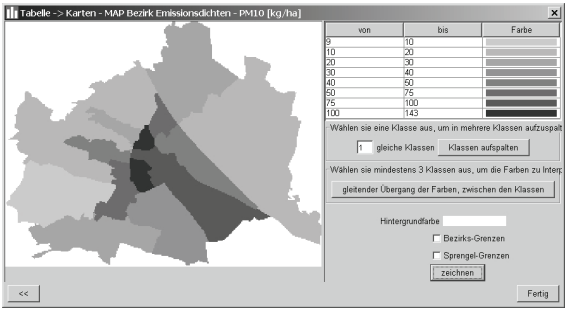

Fig. 2:
PM10 emission densities for the reference year 2003 in the 23 municipal districts (kg/ha)

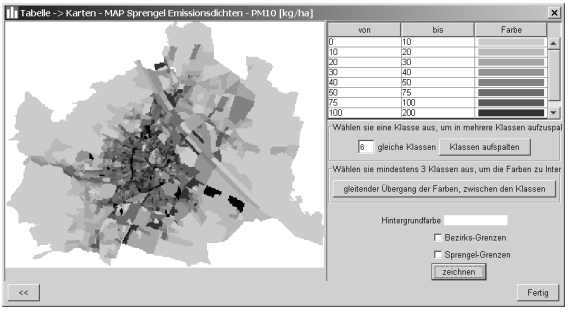

Fig. 3:
PM10 emission densities for the reference year 2003 in the 1 364 census tracts (kg/ha)

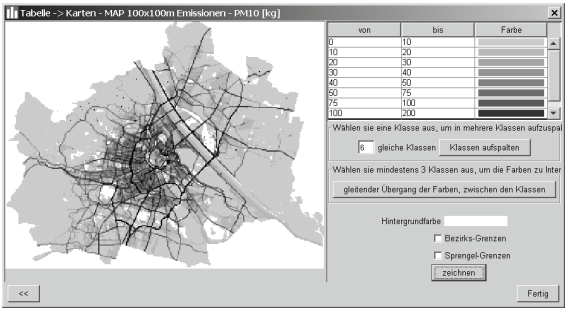

Fig. 4:
PM10 emission densities in 100x100 m grid cells (kg/ha)

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