Emissions inventorying as an integrated part of the state of the art Air Quality Management System, AirQUIS

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ABSTRACT

The Norwegian Institute for Air Research (NILU) has developed a GIS based integrated management system, AirQUIS, which includes a user interface, comprehensive measurement and emission inventory databases and a suite of models for use in simulating ambient air concentrations and exposure.

This paper presents the AirQUIS module for emission inventorying and its use for air quality assessment, modelling and management on urban/agglomeration scale. This tool contains the necessary functionalities for producing a complete, detailed bottom-up atmospheric emissions inventory. Excel based templates have been developed for source and emission data collection, which can be directly imported into AirQUIS database. The emission information in the database is directly accessed by the emission model, which generates the necessary spatial and temporal emission data to be used by the dispersion-model. The emission inventory tool organizes the emission data by three types of source: point, area and line. Emission data are distributed temporally using time variation factors on the average annual emissions.

The emission inventory tool is used to assess the contributions from individual sources, source categories and geographical areas. The GIS platform is used for the visualisation, presentation, update and management of the emission data. Functionalities for studying the impact of emission abatement measures on air quality are also included as part of the emission inventory module in the air quality management system, AirQUIS.

INTRODUCTION

AirQUIS[1] is a GIS based state of the art Air Quality Information and Management System, developed by NILU for air quality assessment and planning purposes. The system includes: 1- On-line data collection from monitoring stations; 2- Tools for statistical evaluation and presentation of meteorological and air quality data; 3- A user friendly emission inventory module and 4- Models for calculating emissions, wind fields, pollutant dispersion and exposure. The system has been applied worldwide for air quality monitoring and to estimate environmental impacts from planned measures to reduce air pollution. It is also a platform for optimal abatement planning and development of action plans.

This paper presents the AirQUIS module for emission inventorying in Section 2. Practical examples on how the AirQUIS emission inventorying module can be applied to assess emissions and study the impact of emission abatement measures on air quality in urban areas are presented in Sections 3 and 4, respectively. Finally, some concluding remarks are offered in Section 5.

## AIRQUIS EMISSION INVENTORY MODULE

The AirQUIS Emission inventory module[2] contains a database for a detailed bottom-up atmospheric emission inventory, directly coupled to the integrated Geographical Information System. It also includes emission models to calculate emissions on the wanted spatial and temporal resolution, as well as functionality for emission assessment and management. The database is a well designed relation-database, and the tool has window based spreadsheets and tree-view functionality. Excel based templates have been developed for source information and emission data collection. These templates are a mirror of the relation database structure, where the data in the templates refer

to data in other templates. The data collected can easily be imported into the emission inventory database by applying normal Windows, "drag-and-drop" functionality.

Data search and filtering can be done by using the modules tree-view, or by selecting the area of interest in the GIS. The GIS module can further be applied to geographical identification of the emission source(s).

The emission inventory module organizes the emission data by three types of sources: point, area and line (Figure 1).

Figure 1. AirQUIS emission inventory framework.
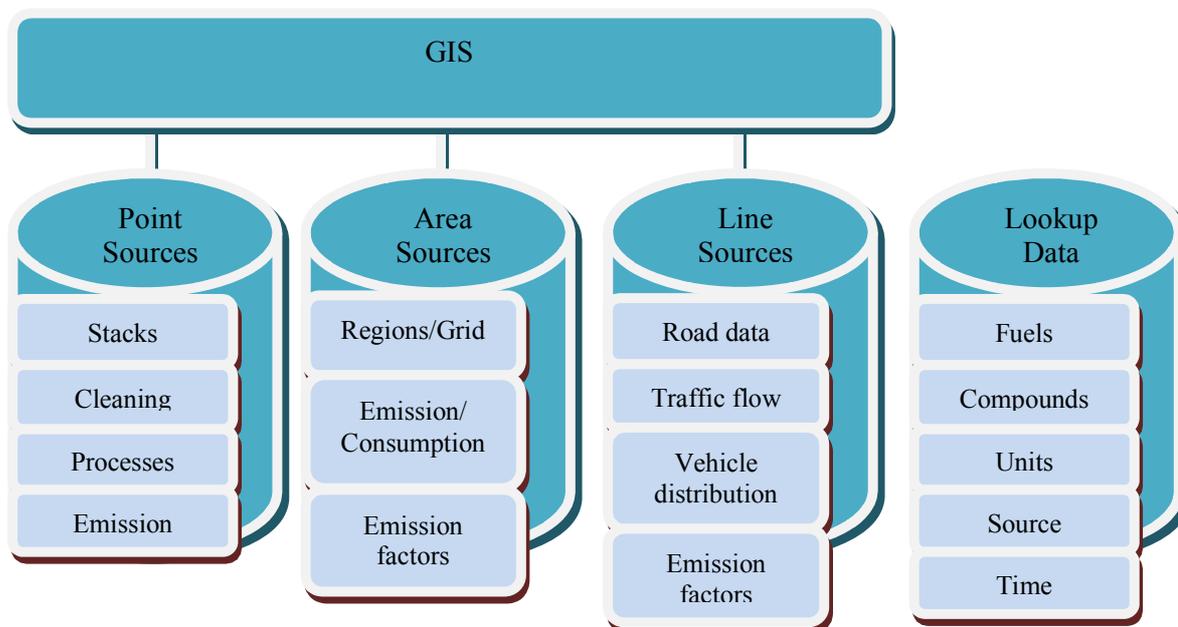
Lookup Data

"Lookup data" include fuels, compounds/parameters, units, source sectors and time variations. Emission sources are commonly classified in a system composed by emission source sectors, sub-sectors and activities (e.g. CORINAIR, AP42). Time variations consist of a series of numbers representing a temporal variation with any degree of periodicity and resolution (week, day, hour or half hour). All "Lookup data" can be user defined according to the emission inventory requirements.

Point Sources

Single sources are called point sources. Stack and vents in refineries and industrial plants are examples of point sources. The "Point source" module (shown in Figure 2) includes general facility identification, emission and release characteristics for each emission point.

Figure 2. "Point source" module.

Point Sources [Regions] - [Source Sectors]

Regions
- Regions
  - 2-AMT Industrial *[0]*
  - 3-Adams Mission *[0]*
  - 4-Adams Rural *[0]*
  - 5-Ak *[0]*

Point Source Register
- Source Sectors
  - 1-Natural Dust   *[0]*
  - 20101-Coal Powder Boiler *[0]*
  - 20103-Gas Boiler *[0]*
  - 201-Power Industry Boiler   *[0]*
  - 20207-Oil Boiler *[0]*
  - 202-Industrial Boiler *[0]*
  - 203-Domestic Boiler *[0]*
  - 2-Boilers and Furnaces   *[0]*
  - 301-Smelting Furnace *[0]*
  - 304-Petrochemical Furnace   *[0]*
  - 305-Thermal Treatment Furnace '
  - 306-Sintering Furnace (ferrous me
  - 311-Electric Arc Oven *[0]*
  - 31404-Hospital Waste Incinerator
  - 314-Incinerator *[0]*
  - 3-Kiln   *[0]*
  - 4-Process Tail Gas *[0]*
  - 5-Dust *[0]*
  - 6-Agricultural waste combustion *
  - 7-Traffic   *[0]*
  - 8-Chemical Process Emission *[0]*

	Industry [16]		Stack [59]		Cleaning Device [14]		Process [100]

	Stack Name	EW-Co.	NS-Co.	Height(m)	Diameter(m)	Gas Temp (degC)	Gas Velocity (m/s)	Gas Flow Rate (m3/s)
1	Paraffin Boiler	-2547.00	-3313136.00	17.00	0.40	179.00	0.30	0.04
2	Associated	-2578.00	-3313124.00	15.50	0.40	41.00	16.60	2.09
3	Associated	-2613.00	-3313108.00	15.50	0.40	81.00	7.50	0.94
4	Tongaat Hulett	-2126.00	-3309594.00	47.50	2.60	187.00	16.40	87.07
5	Ineos Silicas Boiler	-2602.00	-3312611.00	15.00	0.40	120.00	10.00	1.26
6	Ineos Silicas	-2652.00	-3312575.00	46.00	1.60	500.00	5.40	10.86
7	Sapref VBR Stack	-3374.00	-3317230.00	100.00	2.15	338.00	4.00	14.52
8	Sapref CDU 2	-3348.00	-3317078.00	100.00	4.50	308.00	9.00	143.14
9	Sapref Utility Stack	-3273.00	-3317264.00	100.00	1.90	234.00	4.10	11.62
10	Sapref Lubes	-2724.00	-3316301.00	100.00	1.90	258.00	7.60	21.55
11	Sapref Plat Stack	-3004.00	-3316750.00	100.00	2.45	242.00	12.00	56.57
12	Sapref FCCU Stack	-3164.00	-3316930.00	100.00	3.30	300.00	7.50	64.15
13	Tioxide Sulphacid	-9892.00	-3322193.00	40.00	1.20	70.00	23.00	26.01
14	Tioxide Digester	-9945.00	-3322182.00	48.00	1.75	70.00	1.90	4.57
15	Tioxide Digester	-9939.00	-3322193.00	48.00	1.75	70.00	1.90	4.57
16	Mondi Boiler 2	-2911.00	-3315585.00	47.08	2.12	220.00	0.67	2.37
17	Mondi Boiler 1/4	-2943.00	-3315556.00	47.08	2.12	220.00	0.67	2.37
18	Mondi Boiler 5	-3063.00	-3315520.00	46.60	2.12	160.00	10.30	36.36
19	Mondi Boiler 6	-3046.00	-3315533.00	46.60	2.12	160.00	10.30	36.36
20	Mondi Boiler 8	-2929.00	-3315570.00	29.00	1.20	160.00	10.30	11.65
21	IVS 73242 Stack	3937.00	-3307533.00	25.00	0.40	260.00	17.60	2.21
22	IVS DB545 Stack	4057.00	-3307631.00	8.00	0.40	209.00	9.30	1.17
23	IVS DB313 Stack	4256.00	-3307515.00	25.00	0.72	229.00	5.45	2.22
24	IOP Bertrams Stack	-2147.00	-3312690.00	20.00	0.06	311.00	25.00	0.06
25	IOP Babcock	-2151.00	-3312690.00	10.00	0.08	200.00	24.00	0.11
26	IOP JT II Stack	-2141.00	-3312690.00	10.00	0.15	200.00	12.00	0.22
27	IOP JT III Stack	-2151.00	-3312690.00	20.00	0.50	250.00	4.60	0.90
28	Illovo Sugar Boiler	-3860.00	-3313615.00	38.50	0.96	187.00	25.00	18.10
29	Frame HFO Boiler	-3795.00	-3312414.00	25.00	0.90	130.00	10.00	6.36
30	Frame HFO Boiler	-3651.00	-3312233.00	14.00	0.60	160.00	10.00	2.83
31	Frame HFO Boiler	-3643.00	-3312217.00	14.00	0.60	160.00	10.00	2.83
32	Frame HFO Boiler	-3668.00	-3312181.00	14.00	0.60	160.00	10.00	2.83
33	Frame HFO Boiler	-3686.00	-3312171.00	14.00	0.60	1160.00	10.00	2.83
34	Frame HFO Boiler	-3694.00	-3312163.00	14.00	0.60	160.00	10.00	2.83

The information is separated into four major groups: industries, stacks, cleaning devices and processes. Figure 3 shows how an industry is organized into different inventory levels.

Figure 3. Point source emissions inventory levels.

Industry

Cleaning ← Cleaning ← Process 1

Stack 1 ← Cleaning ← Process 2

Stack 2 ← Process 3
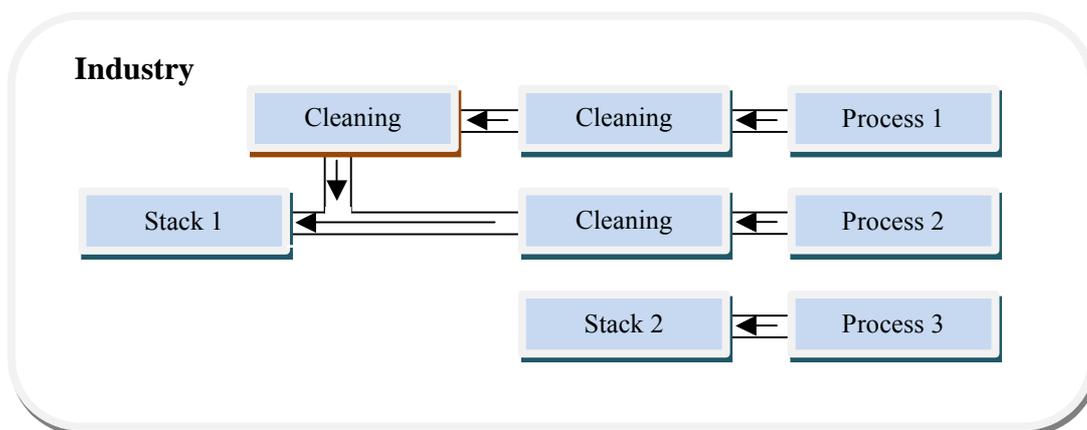
The "industry register" lists all the defined industries and their general facility identification. Physical and geographical information of each stack within an industrial plant is defined in the "stack register" (e.g. stacks height, stack gas velocity and temperature, etc). The "cleaning device register" defines the cleaning devices within an industry, their reduction efficiencies for specific compounds, and which stack (or cleaning device) they are connected to (Figure 3). In the process register one defines the processes' emission data or consumption/production data and emission factors, as well as which cleaning devices and stacks it is connected to (Figure 3). Emission data is stored either as:

1) Yearly emissions connected to a time variation, or
2) Yearly fuel consumption connected to a time variation and a process specific emission factor (i.e. each process has its own unique emission factor), or
3) Coupled to a Continuously Emissions Monitoring System (CEMS) time series with hourly or daily average values.

Area Sources

Area sources are associated with emissions from domestic heating sources, agricultural activities and/or traffic on smaller roads, distributed in administrative regions (polygons) or in a grid.

The "Area source" module (shown in Figure 4) includes definitions of administrative regions and emission data.

Figure 4. "Area source" module.

Emission data is stored either as:

1) Yearly emission connected to an associated region/grid and a user defined time variation,

or

2) Yearly consumption connected to an associated region/grid based time variation, as well as the source sector specific emission factors.

Line sources

Emission from a defined anchored coordinate based road traffic network is regarded as a line source. The "Line source" module includes geographical location and static information of each road link and its dynamic data, such as annual daily traffic and speed limit. In addition, the vehicle distributions for different vehicle classes are defined on each road link.

The information is separated into four classifications: road data, dynamic data, vehicle distribution and traffic emission factors. Road data defines the static road features (shape, width, gradient, etc). Dynamic data gives information about the annual daily traffic (ADT) and average speed. Vehicle distribution gives information about the percentage distribution of the different vehicle classes (light-, medium-, heavy vehicles, etc), and the weekly, daily and hourly variations (i.e. time variation). Traffic emission factors consist of different factors for different pollutants and for each Emission Calculation Vehicle Class. The factors are also dependent on fuel, driving speed, slope and aging factor.

Model calculation

Emissions are calculated based on line-, point-, and area sources. The result from the emission model can be stored as field data sets for area sources, line and field data sets for road links and point data sets for point sources.
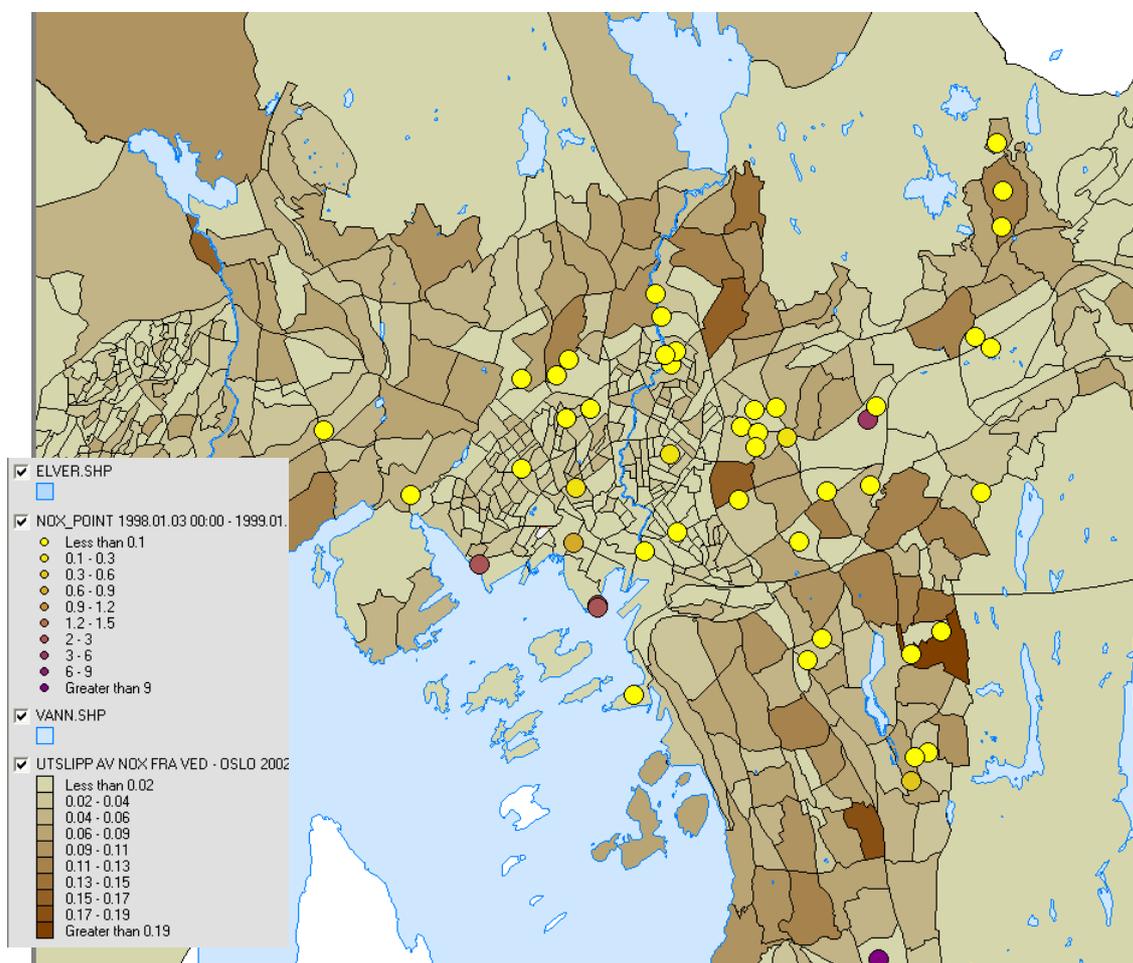
For point sources, the emission from one point source is the sum of the emissions from all processes that are emitting through that stack. For each process, the emission of a certain component is calculated based on consumption data combined with an emission factor, or it is directly given as an emission. After the process emission is calculated or directly given, any reduction that occurs in

the emissions as the gas passes through one or more cleaning devices before it is emitted through the stack must be considered.

Area source emissions are directly given for each activity as emissions from regions or polygons defined in GIS, or they are calculated based on consumption data and an emission factor. The total emission is the sum of the emissions from the different area sources/activities and is then converted from the regions (polygons) values into grid cell (field) values. In addition, emissions from line sources that have been converted to grid cell values will be added to the total area emissions.

The emission of different components from the traffic network is calculated through several steps and it is a function of traffic volume, driving speed, road gradient, calculation year (since this determine the technology level of the vehicles) and the composition and distribution of technology classes. For particles ($PM_{2.5}$ and PM_{10}) the model takes also into account the degree of dryness on the roads based on the meteorological information and the contribution from traffic induced re-suspension of particles[3][4].

EMISSIONS MODELLING AND ASSESSMENT

As presented in Section 2, the emission inventory module organizes the individual emissions sources, e.g. individual stacks and road links. The Geographical Information System - GIS module[5] is directly linked to the emission inventory tool to support the assessment and management of the emission inventory. Connecting emission models to GIS enables the user to map and visualise the spatial distribution and intensity of the emissions, improving its ability to assess and manage the emissions. All data stored in the emission inventory database or calculated by the emission model can be displayed on map, as for example stack heights, emission rates, annual daily traffic, or emissions for each road link. This makes the GIS module an efficient tool for quality control of the emission inventory and assessment of the emissions.

As an example, shown in Figure 5, the presentation of the road link network and corresponding annual daily traffic (ADT) on GIS gives the user the possibility to identify and quality control the traffic data. On GIS, data can both be displayed as colour codes or as numerical values.

Figure 5. Examples of presentation of road network and annual daily traffic (ADT) for each road link using GIS.

Other possibilities implemented in the AirQUIS system for assessment of traffic emissions are:

- Display calculated traffic emissions on each road (line emissions) or within each grid cell (area emission);

- Calculation of emissions from different vehicle classes, e.g. light duty vehicles and heavy-duty vehicle, distinguish between diesel and gasoline cars as well as between different emission standards.

The visualization of area distributed emissions or point sources on GIS together with information about land use or population distribution give a good basis for quality control and assessment. Figure 6 displays annual NOx emissions (tons/year) from woodburning for domestic heating and NOx emissions (g/s) from individual stacks in Oslo.

Figure 6. NOx emission from domestic woodburning distributed on administrative levels (tons/year) and emissions from individual industrial stacks (g/s).

The emission inventory module in AirQUIS includes an aggregation functionality[6], which provides an efficient way to analyse and aggregate emission and consumption data for area sources and point sources from a bottom-up inventory. The user may aggregate consumption and emission data within geographical regions, source sectors, industrial plants, and owners or a combination of these properties. The output from the aggregation module is either a table or a GIS map presenting the aggregated consumption or emission data.

As an example, the Aggregation functionality was used to calculate the point source emissions of NOx by source sectors in Oslo (Figure 7). The major NOx emission point sources in Oslo are plants for district heating and shipping.

Figure 7. Emissions of NOx (tons/year) from individual stacks for Oslo aggregated by source sectors.
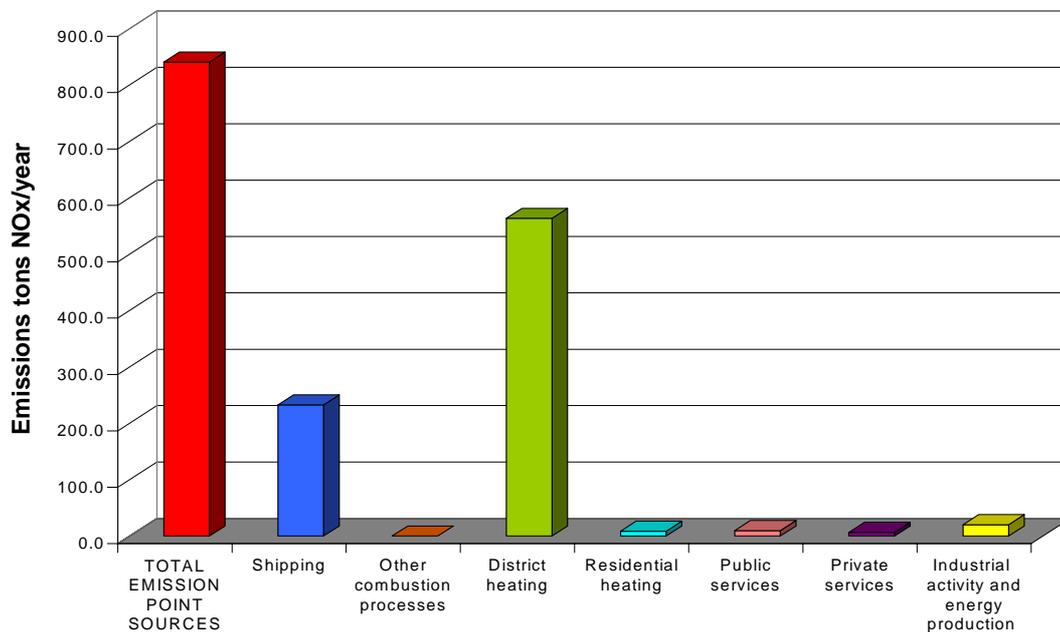
Another feature of this functionality is the possibility of aggregating emissions from area and point sources within regions. One example is the aggregated emissions of NOx from woodburning for domestic heating and from point sources in Oslo, as presented in Figure 8.

Figure 8. Total NOx emissions from area distributed emissions from woodburning and point sources distributed on administrative levels (tons/year).
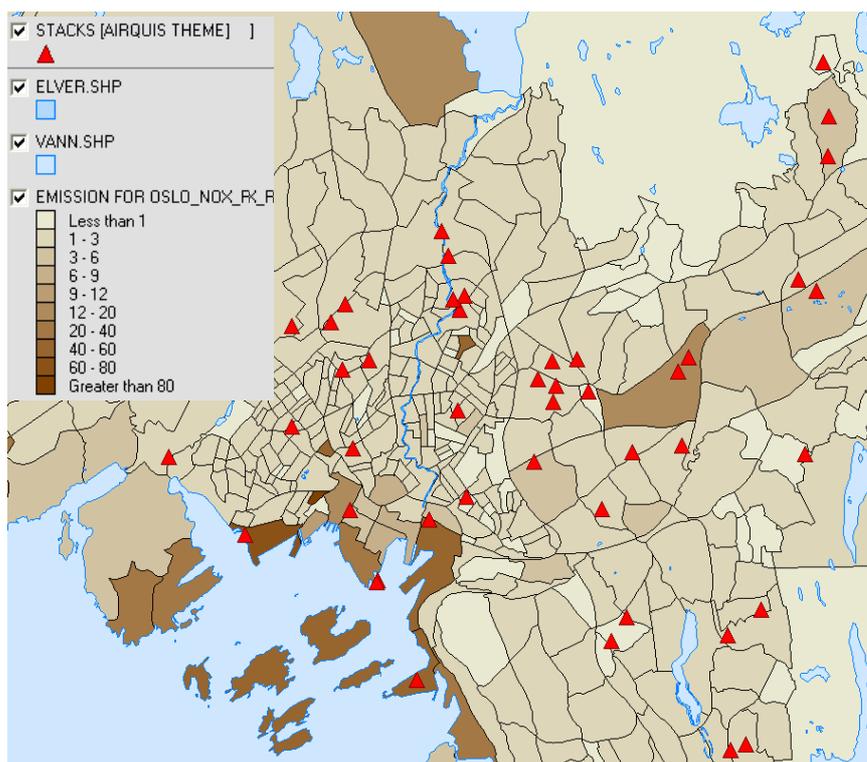
4. EMISSIONS MANAGEMENT

Emissions management is a very important part of air quality management (AQM), as shown by the integrated DPSIR (Drivers-Pressures-State-Impact-Response) framework (Figure 9). AQM involves several tasks closely connected to the knowledge, assessment and management of emissions and emission control measures:

1) Assess the present air pollution situation, relative to standards and guidelines.
2) Develop control options based upon firm knowledge of the sources and its impact.
3) Analyse the effect of abatement measures on emissions, air quality and impacts on health and the environment.
4) Analyse the cost-effectiveness or cost-benefit ratios of the different abatement measures.
5) Select optimal control strategies.

Figure 9. The DPSIR framework will represent an integrated way of handling the air pollution problems.
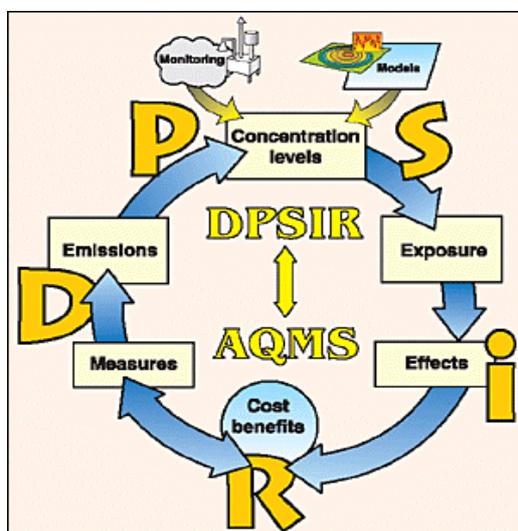
The emission inventory module in AirQUIS includes an efficient tool, the Abatement Functionality, to study the impact of changes in emissions on air quality. The Abatement Functionality makes it possible to carry out changes in emission conditions for line, area and point sources in order to analyse the impact on emission, dispersion or exposure. The changes on emission conditions for area and point sources can be done each individual source, for one or several source sectors, for a geographical area that can be selected using the GIS, or for specific fuel types[7]. For line sources, the emission factors, annual daily traffic, speed and vehicle distribution can be changed for user specified roads, selected geographical areas, road classes, specific fuel types or vehicle classes.

Abatement measure on industrial emissions (Point sources)

As an example on how the abatement module can be applied to study the impact of emission reduction from industry, a case study for Taiyuan (China) is presented here[8]. The emission of SO_2 from Taiyuan Iron and Steel Company is reduced by 2000 tons/year, which corresponds to an emission reduction of 25 % for each of the Iron and Steel Company's stacks. In the "Abatement Scenario" this is defined as a change in the emissions from all the point sources in the industrial plant area selected using the GIS, as shown in Figure 10. The calculated average concentration of SO_2 for the period is shown in Figure 11 on the left; this abatement scenario leads to a reduction of the SO_2

average concentration in the area close to the Iron and Steel Company, compared to the base case scenario shown in Figure 11 on the right.

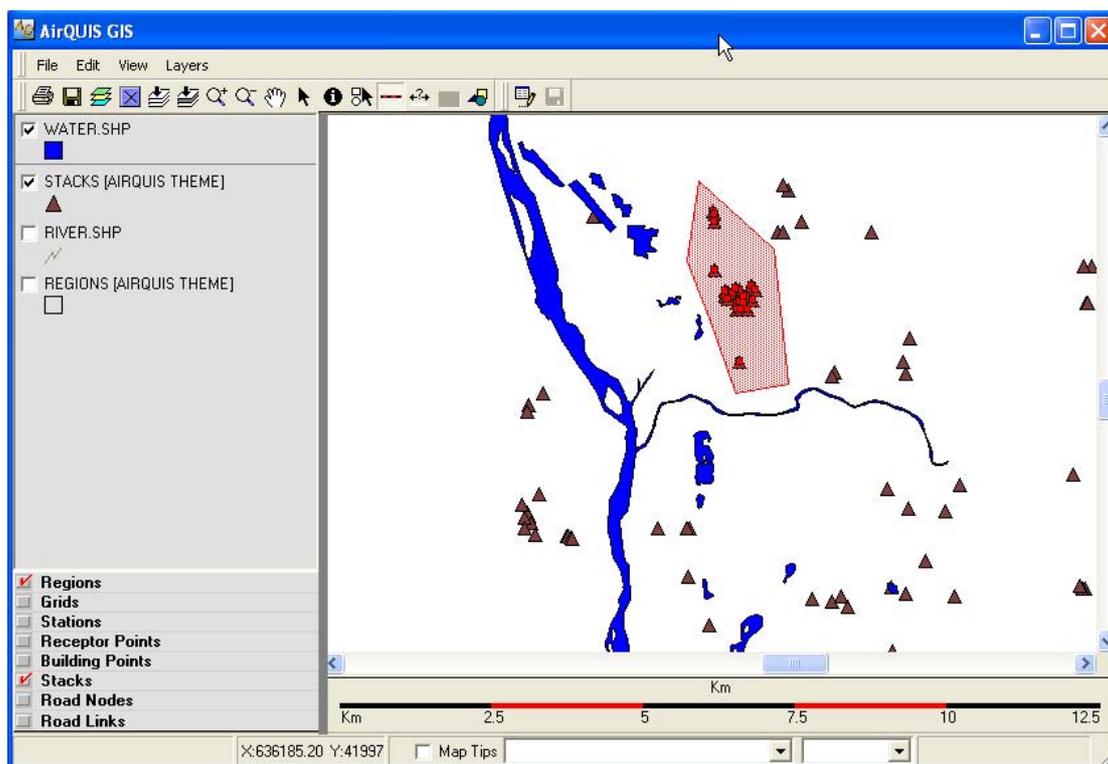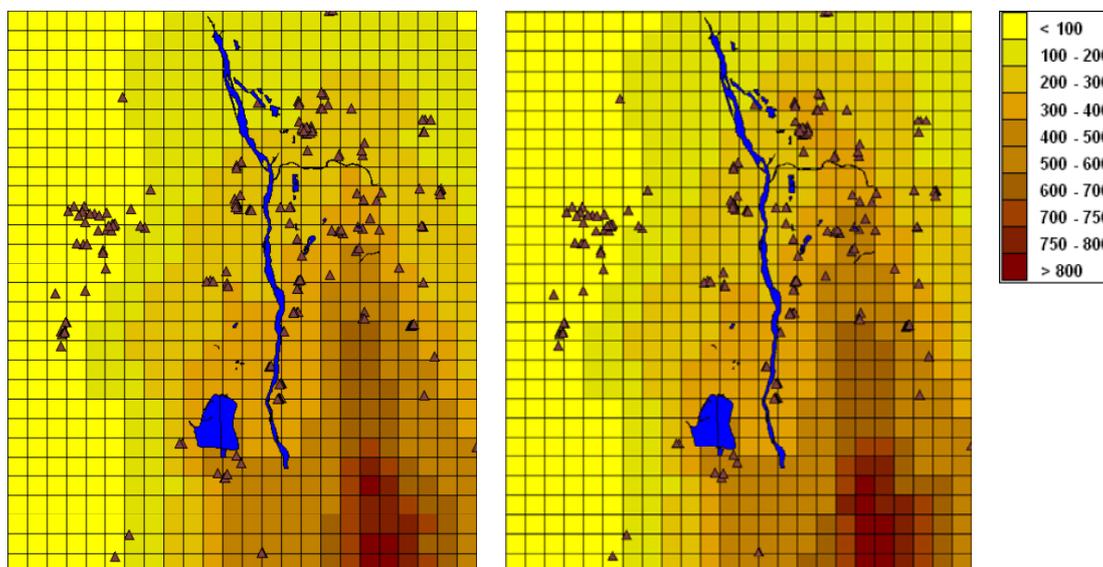**Figure 10.** Selection of polygon containing Iron and Steel Company's stacks.

Figure 11: Left: Average calculated SO_2 concentration in μg/m^3 for the base case emission scenario. Right: Average calculated SO_2 concentration in μg/m^3 for emission abatement at Taiyuan Iron and Steel Company.

Abatement measure on emissions from domestic heating (Area sources)

A case study for impact of emission reduction on domestic heating is presented for Taiyuan, China[6]. The burning of coal in domestic boilers is a major source of SO_2 in Taiyuan. Thus, the Abatement Functionality was used to study the impact of burning briquettes instead of raw coal in

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Xiaodiangu, which is a residential area in Taiyuan. The change from raw coal to briquettes gives a 40 % reduction in the SO_2 emissions. Figure 12 shows how the area of Xiaodiangu was selected from the GIS in AirQUIS. The abatement scenario was defined by a reduction of 40 % on SO_2 emissions from domestic heating within this specified area. Figure 13 (left) shows the calculated average SO_2 concentration in Taiyuan without any abatement, while Figure 13 (right) shows the SO_2 concentration for the same period with the replacement of raw coal by briquettes for domestic heating in Xiaodiangu area. The change of fuel for domestic boilers gives a larger reduction in SO_2 concentration than the previous scenario with changes in industrial emissions.

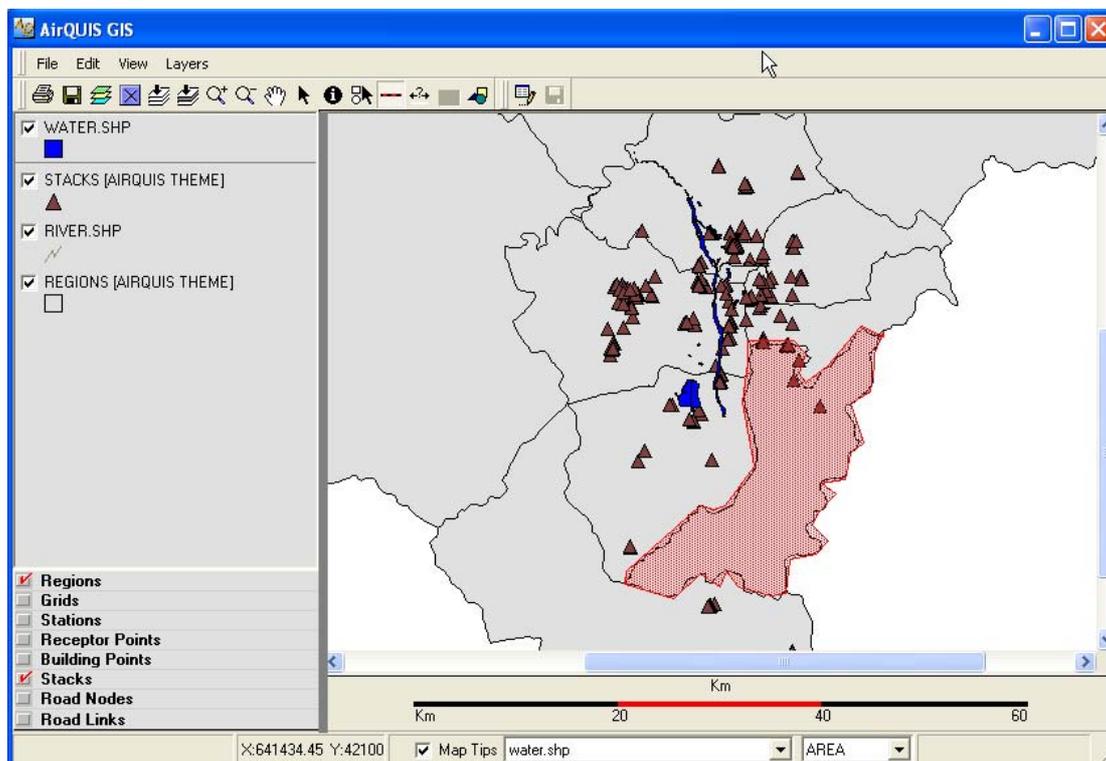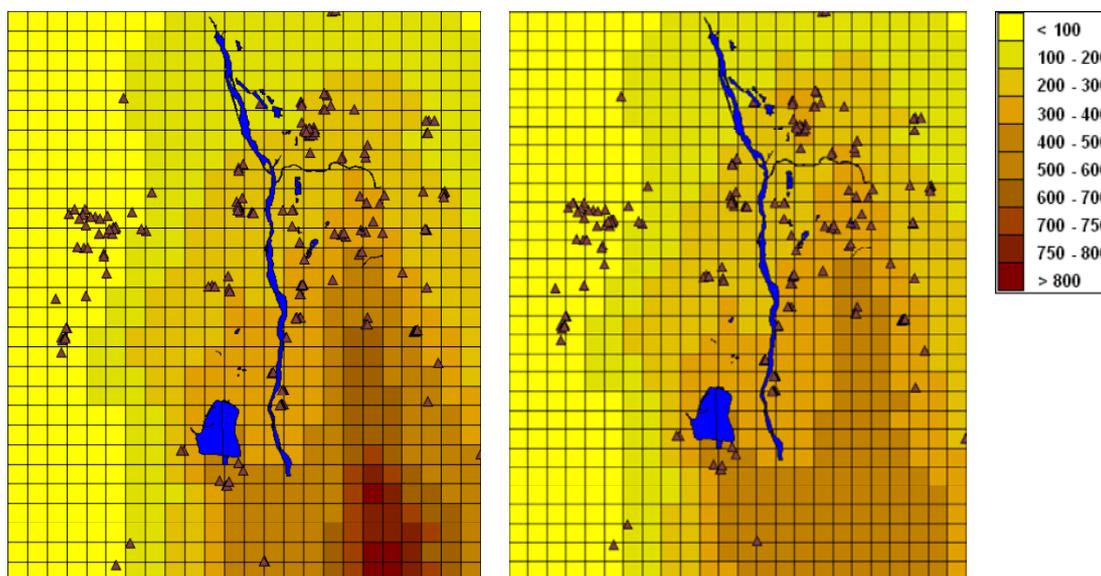**Figure 12.** Selection of polygon containing the Xiaodianqu in Taiyuan.

Figure 13. Left: Average calculated SO_2 concentration in μg/m^3 for the base case emission scenario. Right: Average calculated SO_2 concentration in μg/m^3 with briquettes instead of raw coal in Xiaodiangu in Taiyuan.


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Abatement measure on traffic emissions in Oslo (line sources)

As an example of application of the abatement module for traffic emissions a case for Oslo is presented[6]. In Oslo, traffic is one of the main sources to air pollution. The abatement tool has been used to study the impact of the reduction of the speed limit on major roads is Oslo on the concentration of PM_{10}. The abatement measure consists in reducing the speed limit from 80 to 60 km/h on the highways into Oslo from the northeast. The three different highways are selected by polygons on the GIS interface.

Figure 14 shows the hourly-calculated concentrations from the base case and abatement scenarios at a receptor point located at Furuset, close to the high way. The 20 km/h reduction of the speed limit has a significant effect on the maximum hourly concentration values.

Figure 14. Hourly concentration of PM_{10} at Furuset. Green line is base case scenario and dashed blue line is abatement scenario.
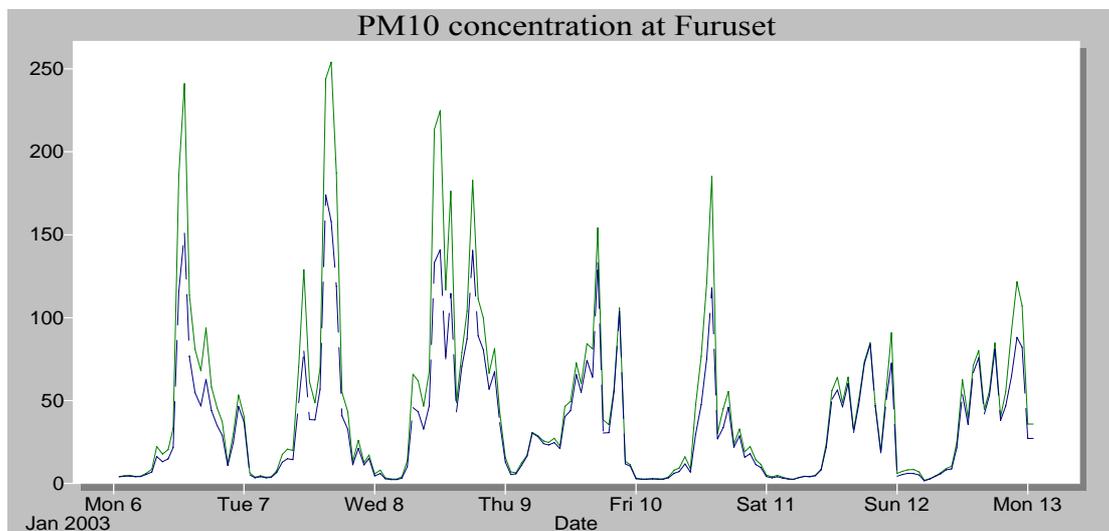
CONCLUDING REMARKS

Air quality assessment requires a variety of tools for data handling and model calculations. The air quality management system AirQUIS has been developed in order to provide easy access to such tools. The combination of a graphical user interface and a flexible database makes the system user friendly and efficient in spite of its complexity.

The AirQUIS module for emission inventorying is a user-friendly tool for producing a complete, detailed bottom up atmospheric emissions inventory for any region or urban areas. The emission inventory tool with the GIS platform for the visualisation, presentation, update and management of the emission data has been successfully used in assessment, modelling and management of air quality on urban/agglomeration scale.

Furthermore, this type of management systems represent an important tool in assessing present and future urban air quality. Recalculations with prescribed changes in emissions can give valuable information on the qualitative effect of various types of abatement measures. Moreover, assessment and presentation on GIS can be helpful in detecting problem areas, as far as air quality is concerned, and thereby provide local authorities with important information with respect to city planning.

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7. KEY WORDS

Air Quality Management
Emission database
Emission assessment
Emission management
Emission modelling
GIS
Abatement measures