

## Lombardy Region (Italy) emission inventory: methodologies and results

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### ABSTRACT

Within the framework of the Regional Air Quality Plan (PRQA) of the Lombardy Region (Italy) a database named INEMAR (AiR EMISSION INVENTORY) was developed for the estimation and management of atmospheric emissions.

The Lombardy Region is a highly industrialized area in the north Italy and has about 9 million inhabitants.

The INEMAR system considers emissions of different sources (point, area, biogenic, road transport), and sets up in a system all information needed for their assessment: activity indicators, emission factors, other necessary statistical data on both the spatial and temporal distribution of emissions.

Emissions' estimates have been calculated by means of a survey of about 300 huge industrial plants and by means of emission factors proposed by the European Guidebook, US-EPA Chief and other Italian data; in some cases specific emission factors from studies carried out within the framework of the PRQA were applied. The methodology proposed by Corinair (Copert II) has been adopted for road transport.

Emissions estimates for the year 1997 are the emissions for 19 pollutants for each of the 1546 municipalities of Lombardy, with relation to about 180 activities (classified in compliance with SNAP 97 nomenclature) and distributed according to fuel type.

The overall emissions' pattern clearly highlights road transport as the major contributor for several pollutants and one of the largest sources of uncertainty at municipality level.

The implementation of the inventory for the year 2000 is on the point of starting.

### INTRODUCTION

#### The Lombardy Region

The Lombardy Region is located in the north of Italy (Figure 1) and has about 9 million inhabitants. The Region is a highly industrialized area, in pole position in the Italian productive system for productivity and range of products.

Characterized by a high density of companies (20 % of the total of companies of national ground), and hosting specialized industrialized districts (such as the textile called "Asse del Sempione" and the wood sector in Brianza, together with the metal, silk and knitting districts in other areas), the Region is experiencing a significant development of private transports. Figure 2 shows the vehicle park at the end of 1997.

The total amount of vehicles every 100 inhabitants is extremely high: the regional average is 84, distributed in 58 cars (more than 1 vehicle every two people), 20 mopeds and motorcycles and about 7 light and heavy trucks.

The Lombardy Region also features several road axes characterized by dramatic traffic volumes. Figure 3 shows average vehicular fluxes in the rush hours on the main highways, in which the great amount of light and heavy trucks, mainly used for goods' transport, can be noticed.

### **The Regional Air Quality Plan (PRQA)**

The emission inventory has been set up in the framework of the Regional Air Quality Plan (PRQA), a three-year, 2 millions Euro Project carried out in cooperation by the Environmental Department of the Lombardy Region and the Fondazione Lombardia per l'Ambiente, a non-profit, research institution established by the Regional Authority which avails herself of the collaboration of the three largest Universities in Lombardy.

The PRQA focuses on a region-wide investigation on air pollution agents, emissions sources and inventories, critical areas' characterization, risk assessment for human health and ecosystems, cost-benefits analysis for mitigation measures.

The Project's planning has been complex and developed according to a scheduled master plan and based on some operational units for coordination and check. These operational units have been divided into 14 operational groups according to the two main phases of Plan:

- the "survey phase", completed in December 2000 and consisting of: territory survey, air monitoring, climate analysis, institutional framework estimation, emission inventory, chemical-physical-meteorological models' definition, economic models, state, impact and pressures indicators' assessment, and finally critical areas' location.
- the "proposal phase", which is still underway and includes scenarios and emissions' predictions, policy proposals in different fields, and implementation instruments.

Once the first phase has been completed, some specific areas with homogeneous features with relation to environmental pressure have been singled out. The possible danger of this pressure has been assessed with the aim of pointing out the priority of different interventions.

The first phase of the Plan has been presented on 1 December 2000 under the chairmanship of the Lombardy Region. A CD-Rom (1) containing all reports in Italian has been supplied to participants and to interested parties.

In the PRQA proposal phase, the implementation of further administrative laws on air quality and emissions' restrictions is under study, on the basis of the evidence collected in the first phase. Further studies are needed in order to better evaluate the dynamics of secondary pollutants as a result of reactive primary pollutants (fine particulate matter, ozone).

## **METHODOLOGY**

### **Pollutants**

The substances taken in consideration in the Lombardy Region 1997 inventory are acidifiers (SO<sub>2</sub>, NO<sub>x</sub>, NH<sub>3</sub>, CO), ozone precursors (NMCOV), greenhouse gases (CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O), heavy metals (As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn). These substances are considered in compliance with the CLRTAP and FCCC Protocols.

PM<sub>10</sub> and dioxin have also been considered, although the emission inventory has been based mainly on US-EPA emission factors.

Greenhouse gases' emissions are not taken in consideration in this paper since a comparison between Corinair and the IPCC methodology is still underway.

## Classification of activities

The Nomenclature used for the Corinair inventory (SNAP 97) (2) has been adopted.

The CORINAIR inventory is designed as a common european-wide data base which is easily applicable to the setting up of specific inventories in accordance with LRTAP and FCCC guidelines.

The SNAP97 system is set up according to three levels:

- the upper level - 11 source categories – which features sources' grouping as commonly performed;
- the intermediate level - 75 source sub-categories (45 of which used in the Lombardy Inventory)-embodying technological and social-economic criteria
- the lower level - 416 source activities (185 of which used in the Lombardy Inventory) - aiming at an exhaustive enumeration of sources and sinks to spot homogeneous sections in generating emissions.

## Point sources

About 300 huge industrial plants have been selected and emission and other surrogate data have been collected by means of a form. The surveyed plants are power plants, cement industries, municipal waste incinerators, refineries, landfill and the largest chemical and manufacturing plants. Emission data on most significant macro-pollutants (SO<sub>2</sub>, NO<sub>x</sub>, dust, CO) are taken from continuous monitoring system.

Within the framework of PRQA, the definition of a computerized network of large plants' emission data is in progress and aims at making them easily available to control authorities and to other interested subjects (universities, research institutions, private companies).

Figure 4 shows SO<sub>2</sub> and NO<sub>x</sub> emissions of the 15 major point sources in Lombardy: they represent about 65 % of SO<sub>2</sub> total Lombardy emissions, though only 12 % of total NO<sub>x</sub>.

## Area sources

Emissions from smaller industrial plants or, in general, area sources' emissions (i.e. emissions from heating plants or agricultural activities) are assessed by the usual methodology based on indicators and emission factors.

The emission factors used in this analysis derive from the European Atmospheric Inventory Guidebook (2), from the U.S.EPA Air CHIEF CD-ROM Version.7 (3), and from Italian data collected by ANPA (4); in some cases, specific emission factors have been applied, coming from studies carried out within the framework of the PRQA.

Specific emission factors for the Lombardy Region have been detected for the following activities:

- combustion in commercial and institutional boilers (< 50 MW);
- combustion in residential boilers (< 50 MW);
- combustion in industrial boilers (< 50 MW);
- paint application: car repairing;
- other use of solvents and related activities, printing industry.

Methodologies proposed by Corinair (5) have been used for road transport emissions, with the basic distinction between non-urban driving (highway and other main roads) and urban driving. Non-urban traffic is the component of road mobility which runs along the roads' network by middle or long-term courses, whereas urban traffic uses it for all kinds of courses along municipal roads (6).

As far as urban driving is concerned, a survey on 18 PUTs (Urban Traffic Plan) has been done, collecting information on vehicle mileage and speed, on daily and seasonal traffic variation. A relation between vehicle mileage and population has been adopted to calculate urban traffic emissions for the 1546 municipalities in Lombardy.

All available traffic data in the Lombardy Region covering 1993 to 1998 have been collected and processed. Traffic data were available for 9000 road sections, 5 vehicle categories (passenger cars,

light duty vehicles < 3.5 t, heavy duty vehicles > 3.5 t and buses, motorcycles > 50 cm<sup>3</sup>).

Data of temporal vehicle distribution have been considered for 4 seasons, 3 different days, 3 different hours. All available data have been processed within the TRIPS (Equilibrium Traffic Assignment Algorithm) model to calculate both traffic flows and speed on all roads in the Lombardy Region (except for smaller roads with local traffic).

As for biogenic emissions (NMVOC emitted by forests), the algorithm developed by Alex Guenther (7), and proposed in the CORINAIR framework (2) has been used.

As for landfill emissions, an algorithm based on the IPCC detailed methodology has been used.

## **The INEMAR database**

The INEMAR (AiR EMISSION INVENTORY) database is a multi-user database in RDBMS Oracle environment based on Alpha server. Inemar contains all data for the emissions' assessment, procedures that develop the algorithms used to carry out these estimates and the values of calculated emissions.

The database can be reached by any PC user connected on the regional ISDN network, through client in MSAccess in order to visualize or modify data in the archive, or for local data processing; moreover, the user interface in the MS-Access environment supports the arrangement of archives for scenarios' simulation.

The output can be visualized, in the client-server mode, with maps, graphs and tables by means of a Nebula LTK specific module, a GIS-oriented package previously developed by the Lombardy Region.

From the main menu (Figure 5) the five section of the database can be reached: point sources, biogenic, residential heating, area source, road transport.

## **RESULTS AND DISCUSSION**

### **Emissions by pollutant**

Estimates for the year 1997 are the emissions for 19 pollutants for each of the 1546 municipalities of Lombardy, with relation to about 180 activities (classified in compliance with SNAP 97 nomenclature) and distributed according to fuel type (8). The emission summary for major pollutants and group of activities (SNAP 97 level 1) appears in Table 1 and in Figure 6.

The main SO<sub>2</sub> emission derives from combustion plants in energy industries, with a contribution amounting to 57% of total emissions. NO<sub>x</sub> main contribution, due to road transport, is about 66% of total emissions of all groups. NMVOC emissions derive mainly from solvents' use, which accounts for 38% of total emissions, and from road transport, which is 43% of total emissions. The most significant source of CO emission is road transport, which accounts for 59% of total emissions. NH<sub>3</sub> emissions is almost entirely due to agriculture and manure management.

The highest heavy metals emissions derive from combustion plants in energy industries, to industrial production processes, road transport and industrial combustion (Figure 7).

PM<sub>10</sub> emissions come from combustion process, with a significant contribution from traffic (Figure 8).

Average dioxin emissions are shown in Figure 9, as well as minimum and maximum emission levels, calculated by means of the US-EPA approach (9). Figure 10 shows the contribution of each different source to average regional emissions. Municipal waste incineration and electric arc furnaces are the main sources of dioxin in Lombardy and their average contribution is 57% on total dioxin emissions, with electric arc furnaces showing the highest value.

Vehicle fuel combustion (leaded and diesel), secondary aluminum smelting, wood residential combustion and cement kilns are the second heavy contributors to regional dioxin emissions, with an average total value of 34%.

### **Emissions by group**

In group 1 (combustion in energy and transformation industries) relevant SO<sub>2</sub> emissions are detected, deriving from residual oil use in combustion plants in energy industries, which also causes significant heavy metals' emissions (As, Cd, Hg, Ni).

Emissions in group 2 (non-industrial combustion plants) are mainly due to residential boilers. As for the distribution per fuel, SO<sub>2</sub> emissions are due to gas oil (63%) and residual oil (32%), whereas NO<sub>x</sub> is produced by methane (51%), gas oil (20%) and residual oil (19%). Contribution of wood to CO and NMVOC emissions is relevant (94% of CO of this group and 81% of NMVOC).

Emissions in group 3 (combustion in manufacturing industries) are mainly due to gas oil and residual oil use in industrial boilers. Emissions of SO<sub>2</sub> are mainly due to cement and glass production (about 72% of total in this group).

The results obtained in group 4 (production processes) show the contribution of petroleum industry to NMVOC emissions from fuels' storage and handling in refineries. More than 90% of SO<sub>2</sub> emitted in this group derives from petroleum refining, whereas contribution of refineries to NMVOC is about 83%. CO emissions are mainly due to processes in metals industry. NMVOC are also emitted by processes in organic chemical industries and by other industries (paper, wood, bread).

Relevant NMVOC emissions in group 5 (extraction and distribution of fossil fuels) come from storage and handling of petroleum products, whereas in group 6 (solvents and other products), high contributions to NMVOC emissions come from painting, from chemical products' synthesis and manufacturing, from the printing industry and the domestic use of solvents.

In group 7 (road transport), non-urban traffic plays the major role in all pollutants' emission. Road transport emissions in 1997 still were the most relevant source of Pb in the atmosphere, even though this contribution is progressively decreasing due to the diffusion of unleaded gasoline.

Emissions in group 8 (other mobile sources and machinery) are mainly due to airport operations.

In group 9 (waste treatment and disposal), solid municipal waste incinerators contribute for 70% to SO<sub>2</sub>, for 65% to NO<sub>x</sub>, for 23% to NMVOC, for 9% to CO total emissions; land fillings, besides the contributions of methane (CH<sub>4</sub>) and carbon dioxide (CO<sub>2</sub>), which were not considered in this paper, give a significant contribution to NO<sub>x</sub> and CO emissions (flaring and motors combustion).

In group 10 (agriculture), relevant NH<sub>3</sub> emissions can be detected in rural areas, whereas in group 11 (other sources and sinks) significant emissions are spotted only for CO (forest fires) and for NMVOC (forests).

Figure 11 shows the total emission density (in kg/km<sup>2</sup>) for SO<sub>2</sub>, NO<sub>x</sub>, NMVOC, CO according to municipalities' extension. A general increase in the emission density proportional to the number of residents in the municipality can be outlined, mostly for CO, coming almost entirely from road transport.

### **Emissions at municipal level and critical point factors**

Within the framework of the PRQA (10) a "global emission" index relative to CO, NO<sub>x</sub>, SO<sub>2</sub>, NMVOC pollutants has been proposed. This index was obtained in the context of a parametric normalization of emission values for each pollutant in the single municipality compared to all municipalities and ranking the municipalities score from 1 to 100. Results are shown in Figure 12.

The highest score for Milan and the hinterland can be immediately noticed, but also other municipalities in the province of Pavia, Brescia and Mantova are involved in significant point sources, as well as several municipalities suffering from the presence of large vehicular running axes, such as the A4 Milan-Brescia -Verona, A1 Milan - Bologna and A21 Modena - Brennero highways.

This work represents so far the first attempt in Lombardy to define the whole regional territory with an aggregated point index for atmospheric emissions. Together with atmospheric emissions data, other 17 parameters among which population density, air quality and the presence of environmentally relevant areas were adopted for the definition of critical areas within the Regional Plan for Air Quality.

### **The role of road transport emissions**

Road transport is one of the main source of pollutants' atmospheric emission (such as CO, NO<sub>x</sub>, NMVOC and N<sub>2</sub>O) in Lombardy.

Figure 13 shows road transport per cent contribution to total emissions, for different municipality classes. Even if the estimate of road transport emissions may suffer possible uncertainties since emissions depend on several factors (vehicle type, average speed, upkeep conditions) which estimation methodologies consider only with rough approximation, data shown in Figure 13 show the relevant contribution of traffic to total atmospheric emissions, mostly in highly populated areas.

An additional study on the sensitivity analysis of mobile emissions in relation with vehicle speed has been undertaken in order to better define the uncertainty of mobile emissions' contribution over the Region. At the time this paper is written, a sensitivity analysis of mobile emissions is still underway, thus final mobile emissions may differ from those presented in this paper.

### **Emissions uncertainty**

Both continue emission data and those assessed by the emission inventory are subject to uncertainties. While for monitoring systems reliability and data quality depends on frequency and efficiency of monitoring systems' maintenance, emission inventories' data quality is linked to data quality control systems, i.e. the algorithm used and the precision of input data.

Although the uncertainty of all pollutant emissions has non been mathematically assessed, according to a preliminary qualitative survey on the reliability of emission factors the main uncertainty proves related to NMVOC and PM<sub>10</sub> emissions.

Uncertainty on urban traffic emissions is mainly due to vehicle speed used in the calculation as well as to the reliability of fuel sale data on a provincial scale as an index of fuel consumption; uncertainty on seasonal, daily and hourly traffic variation could also affect NMVOC evaporative emission.

The periodical update of the inventory and the growing refining of most critical sources' assessment methodologies have been therefore scheduled to achieve the efficient management of air quality.

## **CONCLUSIONS**

This paper has presented the main features of the emission inventory developed in the framework of the Regional Air Quality Plan, the first ever extended emission inventory of the Lombardy Region in Italy.

Although other works are needed and are in progress to reduce emission uncertainties, the detailed resolution of the inventory highlights the role of mobile sources in the emission of NO<sub>x</sub>, NMVOC, CO and PM<sub>10</sub> for a large number of municipalities over the region.

One of the major results of this work is the INEMAR database, whose strength can be found in the high resolution (municipality level) of emission results, the great flexibility (DataBase in 3rd normal form), and the client-server framework suitable for provincial inventories. The results on non-urban (highway, other main routes) and urban driving emissions at municipality level are mostly significant, and allow the Regional Authority to consider the efficiency of different traffic limitation interventions on a local scale.

The Inemar system is the first Italian experience of an emission inventory source code developed by a regional authority, thus suitable to implementation and development.

Future planned activities on the Inemar database include the following:

- harmonization of the emission inventory with the IPCC methodologies
- insertion of all warming gases in the emission inventory (SF<sub>6</sub>, HFC, PFC)
- uncertainty analysis for warming gases' emissions in Lombardy (Monte Carlo simulations)
- definition of emission factors for specific activities (CH<sub>4</sub> from landfills, CH<sub>4</sub> from agriculture, N<sub>2</sub>O from combustion in power plants, CH<sub>4</sub> and N<sub>2</sub>O from waste water treatment)
- use of Inemar by other Italian Regions (i.e. the Piedmont Region) and by the provincial offices of ARPA (the regional official body charged of environmental monitoring)
- web version of Inemar

## ACKNOWLEDGMENTS

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## KEYWORDS

Emission inventory, Italy, Lombardy Region, mobile sources, database.

**Table 1.** Summary of atmospheric emissions (t/y) in the year 1997 in the Lombardy Region

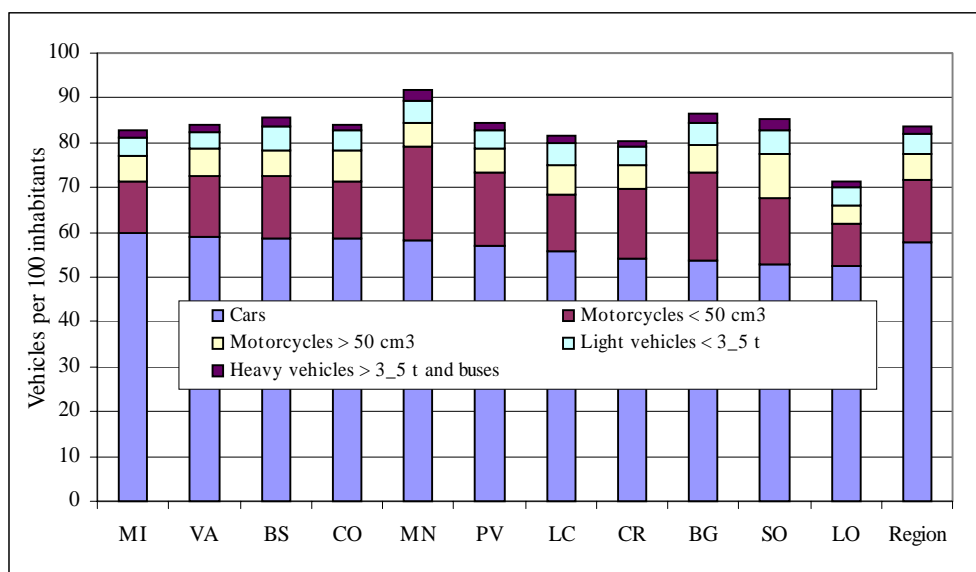
GROUP DESCRIPTION		SO <sub>2</sub>	NO <sub>x</sub>	NMVOC	CO	NH <sub>3</sub>
1	Combustion in energy and transformation industri	52,800	29,000	590	3,700	-
2	Non-industrial combustion plants	5,900	16,100	11,100	119,800	
3	Combustion in manufacturing industry	22,800	49,000	3,600	54,200	-
4	Production processes	3,300	3,100	29,700	84,800	1,800
5	Extraction and distribution of fossil fuels			11,300		
6	Solvent and other product use	-	310	182,700	-	10
7	Road transport	4,900	229,300	204,200	488,900	1,100
8	Other mobile sources and machinery	1,700	17,800	2,400	6,600	-
9	Waste treatment and disposal	380	1,100	950	410	
10	Agriculture		560	920	15,500	113,800
11	Other sources and sinks (nature)	440	1,900	31,900	55,900	440
<b>Total</b>		<b>92,500</b>	<b>348,400</b>	<b>479,800</b>	<b>830,300</b>	<b>117,200</b>



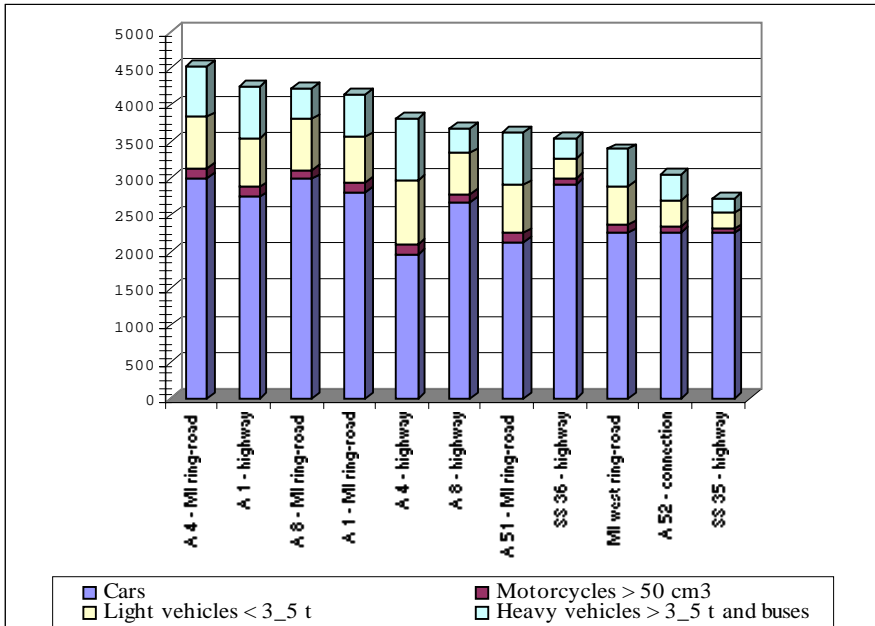
**Figure 1.** Location of the Lombardy Region in northern Italy



**Figure 2.** Vehicle park in the 11 provinces of the Lombardia Region



**Figure 3.** Average rush hour vehicle fluxes on the main highways



**Figure 4.** SO<sub>2</sub> and NO<sub>x</sub> emissions in the 15 major important point sources

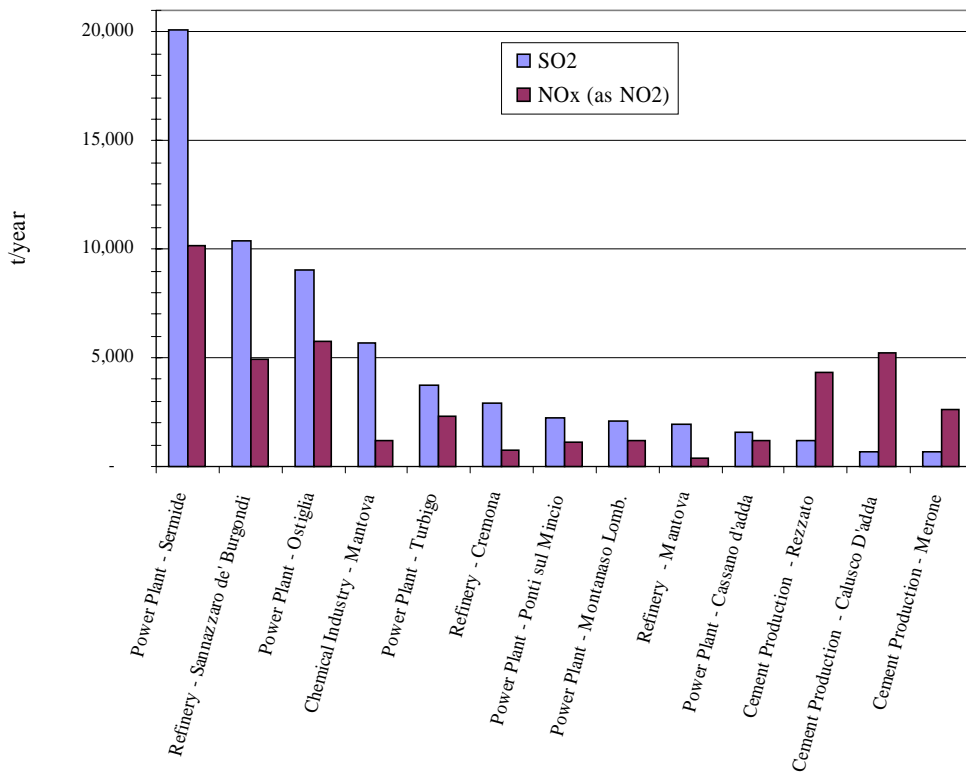
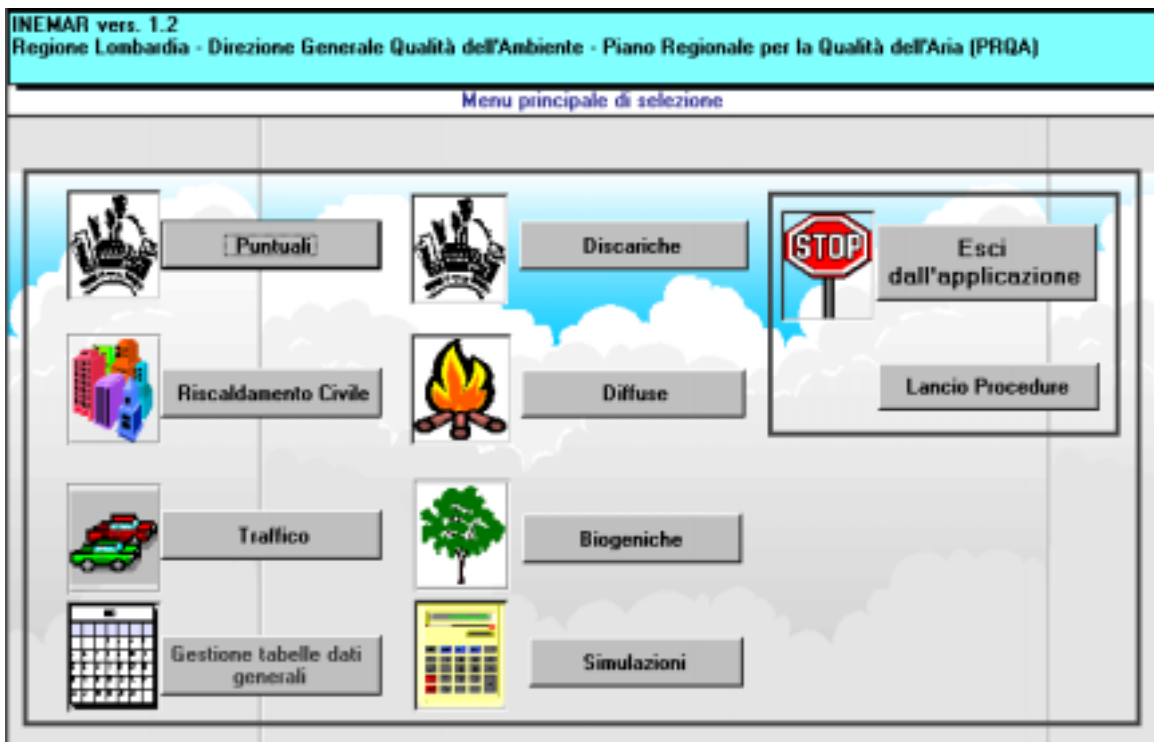
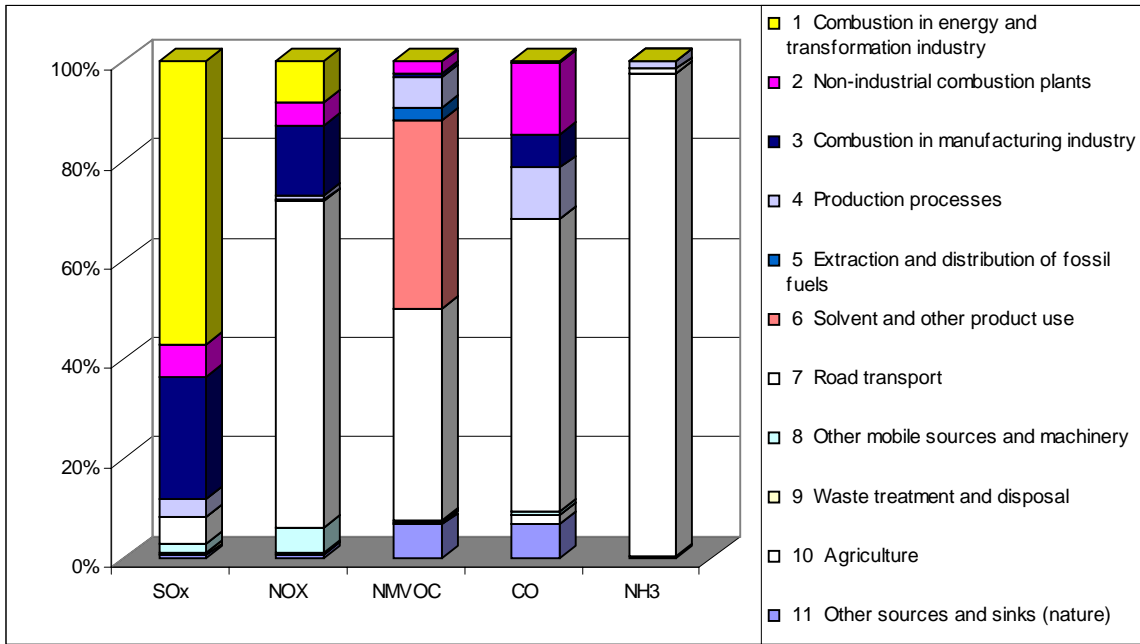


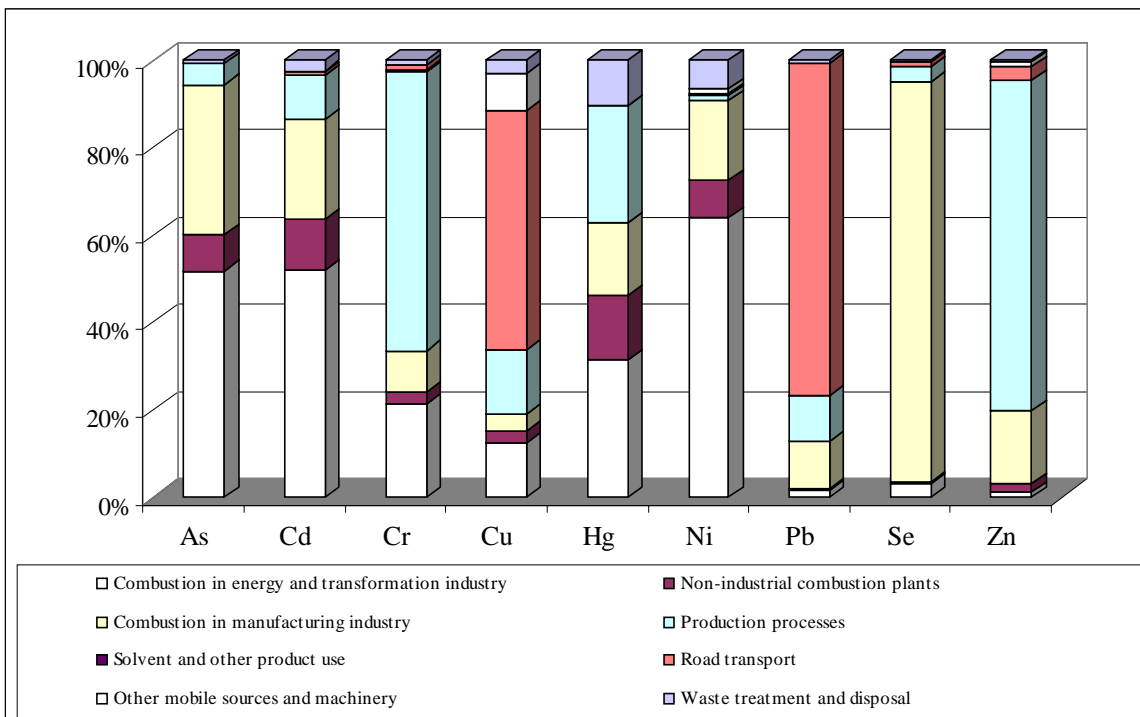
Figure 5. INEMAR database main menu



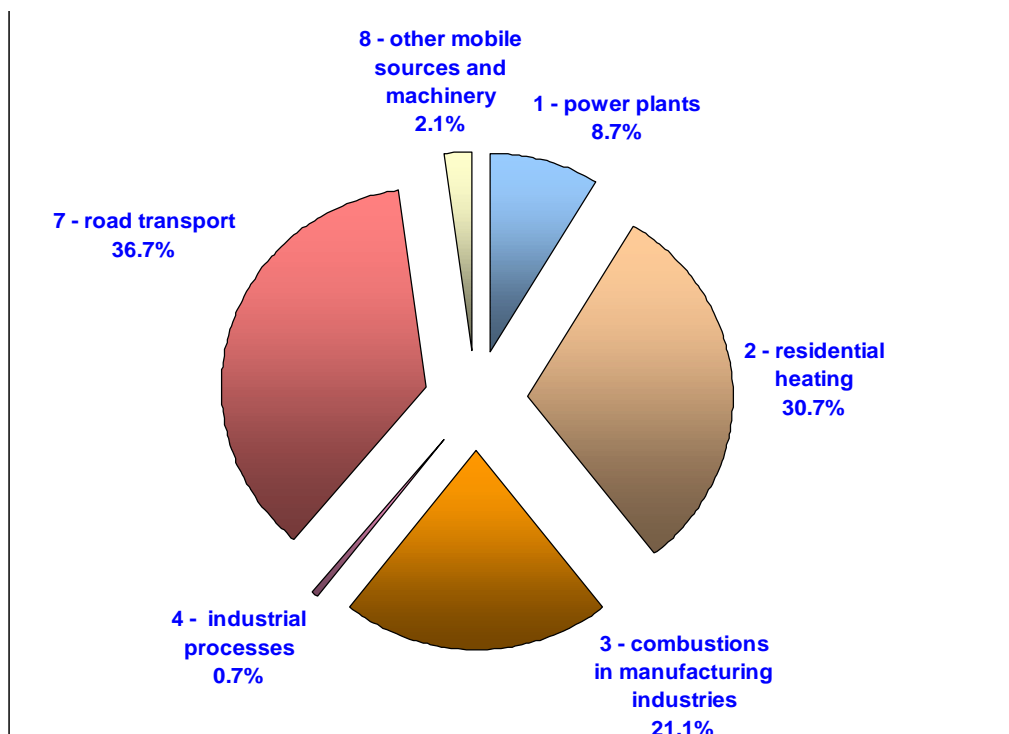
**Figure 6.** Emissions of macro-pollutants by group



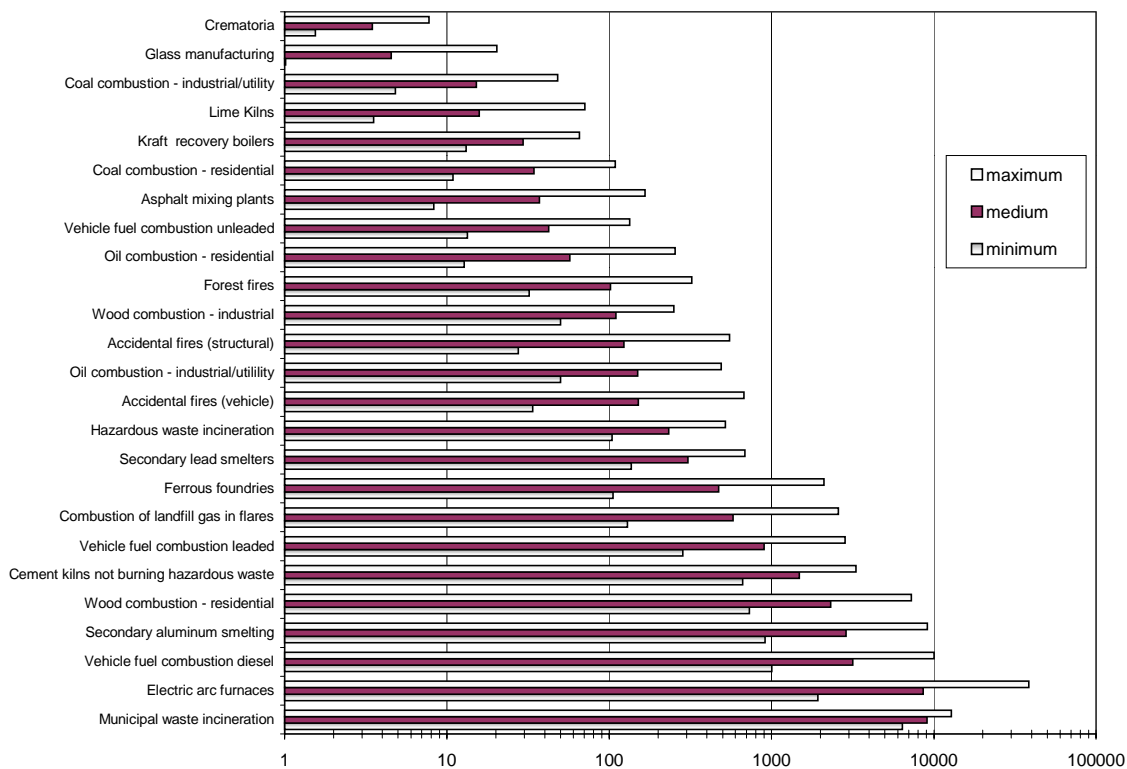
**Figure 7.** Emissions of heavy metals by group



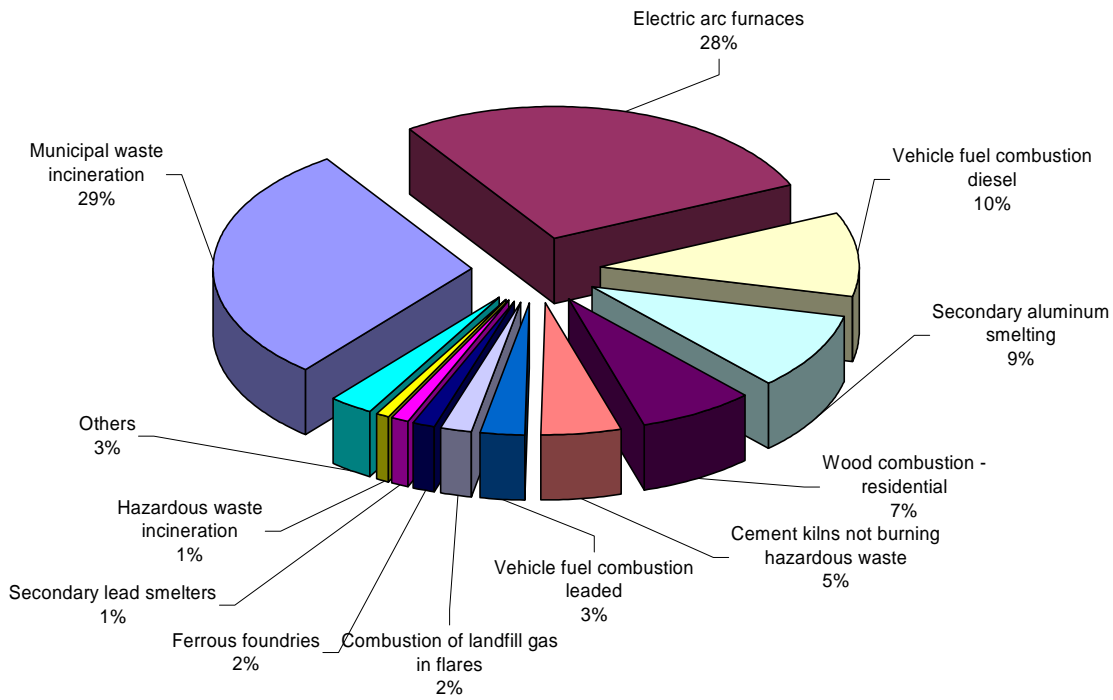
**Figure 8.** Emissions of PM10 by group



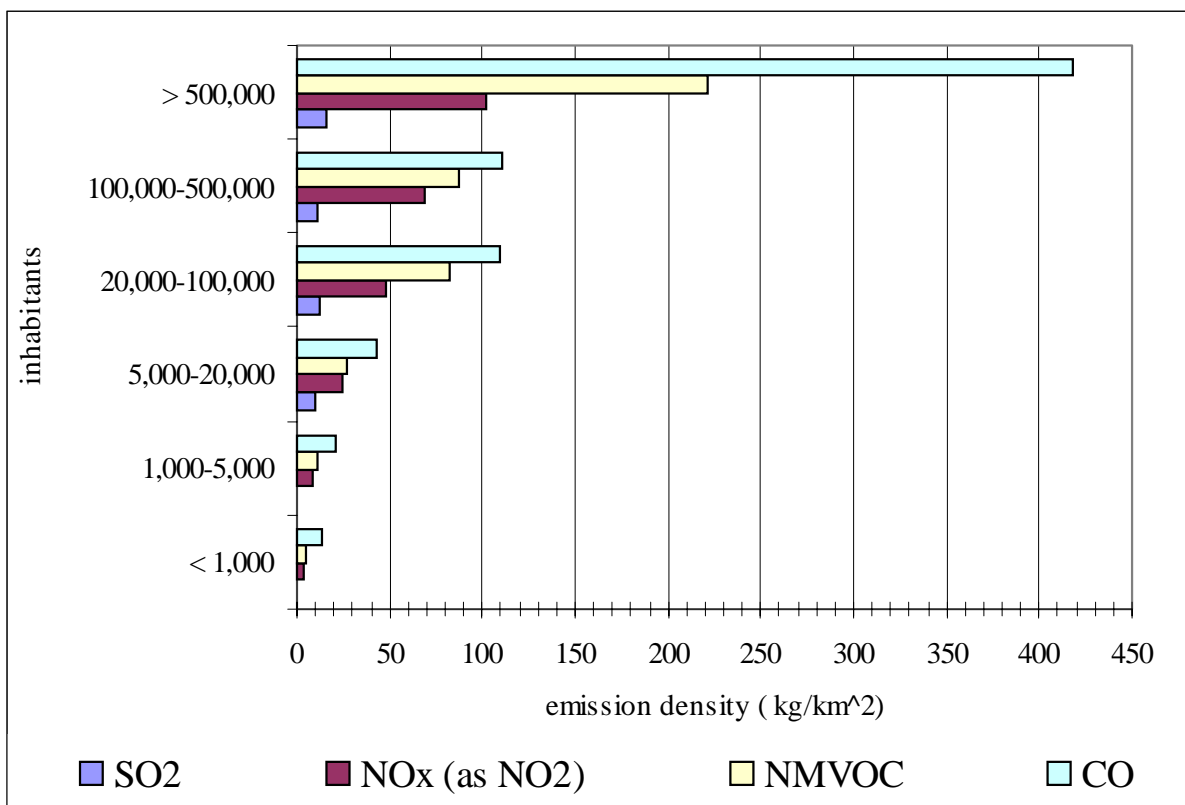
**Figure 9.** Minimum, medium and maximum dioxins emission for different activities (mgTEQ/y)



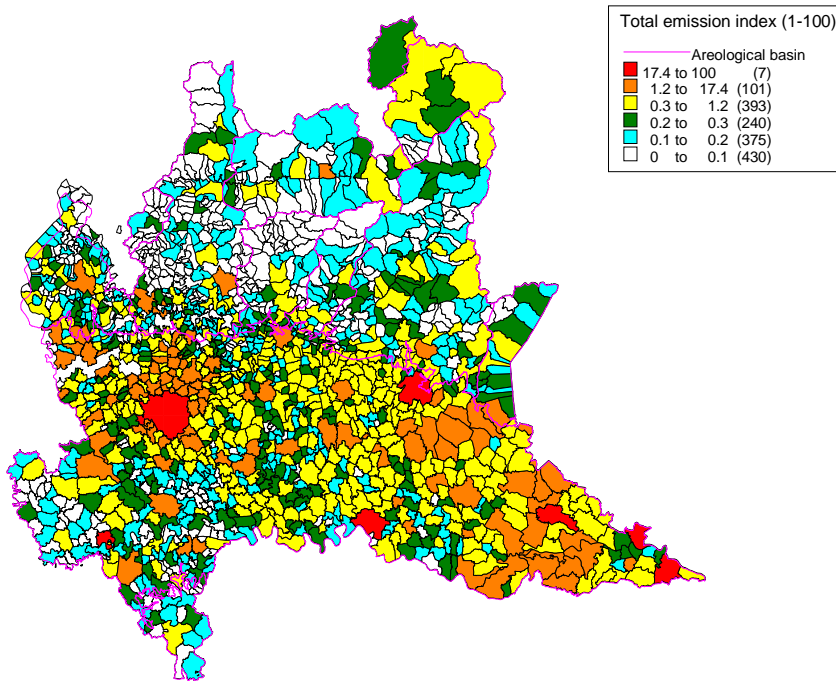
**Figure 10.** Dioxins percent emission for different activities



**Figure 11.** Total emission density for SO<sub>2</sub>, NO<sub>x</sub>, NMVOC, CO for different municipality classes



**Figure 12.** Distribution of “global” emission index concerning SO<sub>2</sub>, NO<sub>x</sub>, NMVOC, CO (10)



**Figure 13.** Road transport percent contribution to total emissions for different municipality classes

