Lombardy Region 2001 Emission Inventory: a tool for air quality planning at different spatial scale

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ABSTRACT

The Lombardy Region (Italy) Atmospheric Emission Inventory, developed for the estimation and management of the atmospheric emissions, is illustrated.
The inventory is based on a database named INEMAR (AiR EMission INventory), developed within the framework of the Air Quality Management Plan of the Lombardy Region, and now managed by Air Sector of ARPA, Regional Environmental Protection Agency.
The INEMAR system considers emissions from different types of sources and is organized into 8 main modules (point, area, agriculture, biogenic, road transport, air traffic, tank, landfill ones) to manage all data (i.e. activity data, emission factors, surrogate variables necessary for the emissions spatial distribution) and algorithms needed for their estimation.
After the inventory for the base year 1997, INEMAR has been used for the 2001 emission inventory, that considers about 220 activities and 15 pollutants.
Emission data are available to the public at the INEMAR web site page. Emissions can be downloaded, for each of the 1546 municipalities of Lombardy, selecting pollutant, activities (classified according to SNAP '97 nomenclature) and fuel type.
Emissions estimates were calculated both by means of a survey of about 250 big industrial plants and by means of emission factors and methodologies proposed by EMEP-Corinair Emission Inventory Guidebook, US-EPA Chief and other Italian data. The COPERT III methodology proposed by EMEP-Corinair have been adopted for computing road transport contribution, with a detailed specification for PM10 based on other European data.
The INEMAR outcome knowledge of the overall emissions patterns at different spatial scales is an essential tool for air quality planning for regional, provincial and municipal authorities in Lombardy and represents a precious data source for other public and private environmental organizations.

INTRODUCTION

The Lombardy Region, with about 9 million inhabitants, is a highly industrialized area, in pole position in the Italian productive system for productivity and range of products.
Characterized by an high density of companies (20 % of the total 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 characterized by a significant development of private transports, with a an extremely high use of the personal motorized vehicle (a regional average of 76 vehicles every 100 inhabitants, 61 of which cars, and 7 mopeds and motorcycles) (1).
The air emission inventory has been set up in the framework of the Regional Air Quality Management Plan (PRQA) by the Environmental Department of the Lombardy Region, and now it's managed by Air Sector of ARPA, Regional Environmental Protection Agency. The inventory focuses on a region-wide investigation on air pollutants, emissions sources and critical areas' characterization, for undertaking air quality planning and mitigation measures. After the first 1997 emission inventory (2), the new 2001 edition has been concluded in

October 2003; data have been available on the INEMAR web page (3) from november 2003 for a public review.

METHODOLOGY

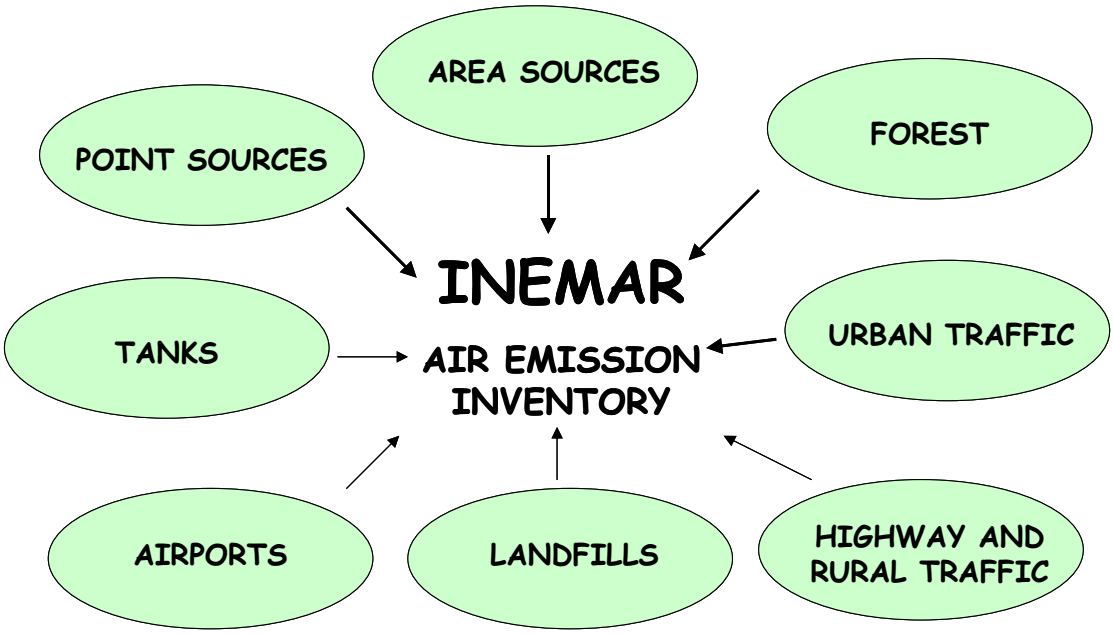
Pollutants

The substances taken into consideration in the Lombardy Region 2001 inventory are acidifying substances (SO_2, NO_x, NH_3, CO), ozone precursors (NMVOC), greenhouse gases (CO_2, CH_4, N_2O), PM10 and dioxins. Although a first inventory of heavy metals (As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn) emissions has been made, the quality assurance - quality control (QA/QC) phase is still on-going.

Classification of activities

The Nomenclature used for the CORINAIR inventory (SNAP - Selected Nomenclature for Air Pollution 97) (4) has been adopted.
The SNAP 97 system is set up according to three levels: an upper level of 11 source categories, an intermediate level of 75 source sub-categories (48 of which used in the Lombardy Inventory) emboding technological and social-economic criteria, and the lower level of 485 source activities (220 of which present in Lombardy).
Emissions are calculated through different algorithms (Figure 1), as described in the following paragraphs.

Figure 1 – Main modules in INEMAR system



Point sources

About 250 big 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 and the largest chemical and manufacturing plants. Generally, emission data relative to the most significant macro-pollutants (SO_2, NO_x, dust, CO) are taken from continuous monitoring system or by single measurement, and are computed basing on specific data of the plant (flue gas concentration, flow rate, temperature, etc.); for other pollutant, specific data of the plant as activity rate, number of employees, etc. have been used together with emission factors taken by literature (point – sources).

Area sources

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

Activity data are generally collected into the best detail, from survey forms filled in by major industrial plants (point data), from statistical surveys on provincial and regional scales or from trade associations data. Emission factors used in the 2001 inventory derive from different sources as European Atmospheric Inventory Guidebook (4), U.S.EPA Air CHIEF (5), Italian data collected by APAT-CTN ACE (National Topic Centre for Air Climate and Emissions) (6). Other data sources found in literature have been used for PM10 (7, 8, 9) and for Dioxin (10).

Traffic emissions

Algorithms proposed by Corinair COPERT III methodology (11) have been used for road transport emissions computation, with the basic distinction between non-urban (highway and other main roads) and urban driving. Non-urban traffic is the component of road mobility which runs along the main roads' network, whereas urban traffic includes all kinds of trips along municipal roads.

An extensive amount of traffic data available in the Lombardy Region covering 1995 to 2001 have been collected and processed. Traffic data were available for 9000 road sections, 4 vehicle categories (passenger cars, light duty vehicles < 3.5 t, heavy duty vehicles > 3.5 t and buses, motorcycles > 50 cm^3). Various vehicles temporal distribution profiles have been considered for 4 seasons, 3 different days (workday, Saturday and Sunday), 3 different hours. All available data have been processed by an Equilibrium Traffic Assignment Algorithm model to calculate both traffic flows and driving speeds on all the Lombardy Region road network, including all the main roads except for smaller ones with local traffic and side streets.

Urban traffic emissions have been calculated on the base of the difference between the total fuel sold in Lombardy and the fuel used by the vehicles on main roads. The allocation of the total regional urban emissions to the 1546 municipalities of the region has been made on the base of a surrogate variable given by the product of the vehicles number at municipal level multiplied by the annual average mileage per vehicle type and the fuel consumption.

Other methodologies

For biogenic emissions estimate (NMVOC emitted by vegetation) the algorithm, developed by A. Guenther (12) and proposed in the CORINAIR methodology (4), has been used.

An algorithm based on the IPCC (Intergovernmental Panel on Climate Change) detailed methodology has been involved in landfill emissions estimate, basing on data collected through a survey on all the landfills existing in Lombardy.

The methodology developed by API (American Petroleum Institute) and adopted by EPA, has been used to assess NMVOC emissions from tanks. Storage and technical characteristics tanks data from chemical, petroleum and refinery plants have been collected.

Emissions from airport traffic have been achieved making use of CORINAIR methodology based on landing/take-off cycle data, for domestic and international aviation, considering flights number per hour and aircraft categories distinction, in Linate and Malpensa airports.

Agriculture emissions come from enteric fermentation, manure management (housing, storage and land spreading) in animal husbandry and from fertilized agricultural land for different type of crop. CORINAIR approach has been used in this case as well, and specifically, for agricultural soils contribution an algorithm, based on fertilizer type sales, nitrogen crop requirements and agrarian tilled area, has been applied to provide municipal emissions.

Due to the lack of PCDD/Fs data measured at the plant and to the uncertain nature of the documentation available on emission factors, a more detailed approach has been chosen for dioxin, aiming at assessing the possible emission variation range of each source (13). Following the methodology used in other emissions inventories (10), a confidence rating scheme is used, assigning high, medium or low confidence for both the emission factor and the activity term.

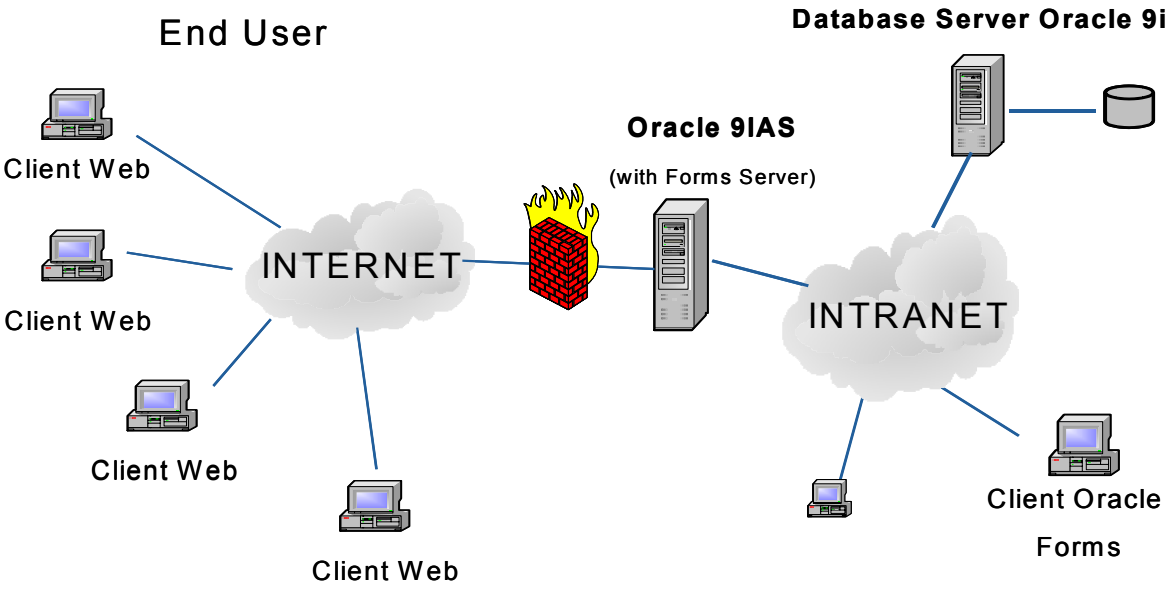
The INEMAR database

The INEMAR (AiR EMission INventory) database is a multi-user database in RDBMS Oracle 9i. INEMAR contains all input data for emission estimates, the procedures to carry out the computational algorithms and the output values of calculated emissions. Algorithms are implemented as packages with Oracle PL/SQL language. To plug in/ change data which foster database INEMAR some forms with Oracle Forms 6i have been carried out.

These forms can be used in the client-server mode or via web browser, changing automatically forms in applet java (Oracle Form Server, Jinitiator), through a three levels structure based on Oracle Applications Server 9IAS (Figure 2).

The output can also be visualized with maps, graphs and tables by means of a specific module of Nebula LTK, a GIS-oriented package previously developed by the Lombardy Region (14).

Figure 2 – Physical architecture of INEMAR



RESULTS AND DISCUSSION

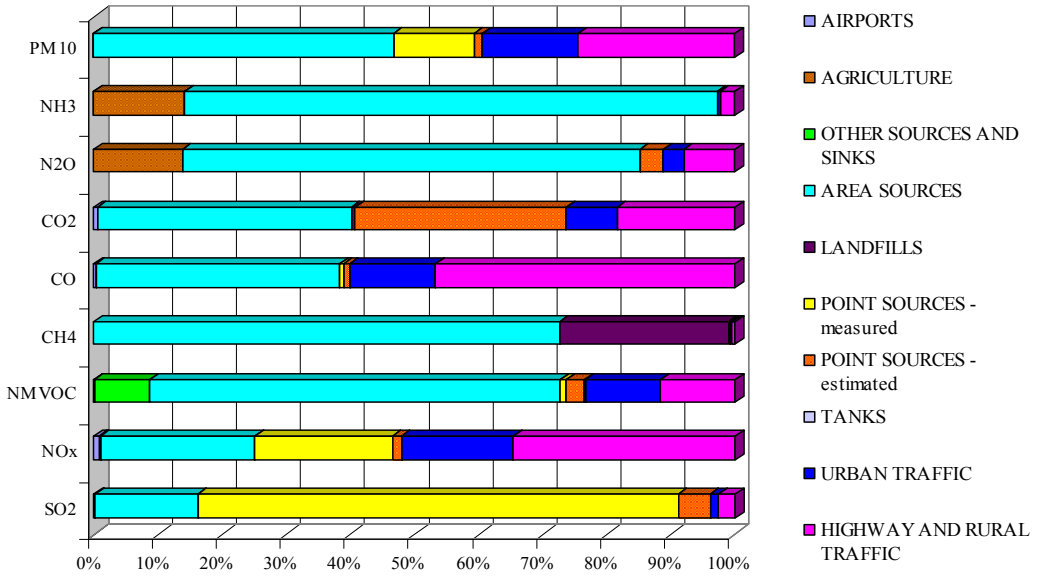
Emission summaries for major pollutants and group of activities (SNAP 97 level 1) are listed in Table 1.

Table 1 – Emissions in Lombardy Region for 2001 (in t year^{-1} unless CO_2 in kt year^{-1}

	SO_2	NOx	VOC	CH_4	CO	CO_2	N_2O	NH_3	PM10
1-Combustion in energy and trasformation industries	51.456	26.996	689	710	2.064	16.404	273	1,8	1.990
2-Non-industrial combustion plants	6.244	16.977	13.946	7.720	163.709	16.931	1.837	209	4.662
3-Combustion in manufacturng industry	10.304	44.554	5.064	1.121	59.114	13.688	743	12	1.006
4-Production processes	3.524	1.594	30.173	138	24.205	3.890	19	73	1.563
5-Extraction and distribution of fossil fuels and geothermal energy			8.919	92.143					
6-Solvent and other product use	1,4	306	148.410		1,6			16	212
7-Road Transport	2.913	114.151	72.704	3.079	434.646	18.794	1.740	2.504	8.480
8-Other mobile sources and machinery	1.202	11.320	1.697	32	5.254	969	246	1,6	1.430
9-Waste treatment and disposal	271	1.778	268	116.917	150	813	147	3,7	75
10-Agricolture		1.568	1.301	216.520	23.314	0	10.656	94.823	1.684
11-Other sources and sinks	83	364	27.787	5.688	10.477	0	12	83	463
Total	**75.998**	**219.610**	**310.957**	**444.069**	**722.935**	**71.490**	**15.672**	**97.728**	**21.565**

The main SO_2 emission derives from combustion plants in energy industries (68% of total SO_2 emissions), whereas NO_x main contribution, road transport, accounts for about 52% of total NO_x emissions. NMVOC emissions derive mainly from solvents use (48%) and road transport (23%); road transport is also the most significant source of CO emission (60%). CH_4 (49%), N_2O (68%) and NH_3 (97%) emissions are almost entirely due to agriculture and manure management. PM10 emissions come mainly from road transport, 39% of total PM10 emission, while energy production, residential and industrial combustion process make an other 36%. Considering different type of INEMAR modules, emissions calculated through area sources methodologies are the most important contribution for all the pollutant except SO_2, that came mainly by an assessment related to declaration by the plant (Figure 3).

Figure 3 – Emissions in Lombardy Region for 2001 (in t $year^{-1}$ unless CO_2 in kt $year^{-1}$) divided for different algorithms of INEMAR.



Hourly emissions due to airport operations are shown in Figure 4, whereas different types of waste disposal emissions are compared in Figure 5.
Emission summary for major pollutants and fuels is shown in Figure 6.
The main SO_2 emission is caused by fuel oil in combustion with a contribution amounting to 60%, while NO_x derive from diesel vehicle in road transport (34%). NMVOC, CH_4, N_2O and especially NH_3 emissions are indipendent from any fuel use.
Gasoline, unleaded gasoline and wood contribute on the whole for 78% to CO emission.
An important share of PM10 comes from wood combustion, mainly in residential fireplaces and stoves.
Dioxin emission reported in Figure 7 show the uncertainty related to the emission inventory for this pollutant. Secondary aluminum smelting and electric arc furnaces are the main sources of dioxin in Lombardy and their average contribution is 70% on total dioxin emissions.

Emissions uncertainty
Both measured emission data and those assessed by the emission inventory are subject to uncertainties. While, for monitoring systems, reliability and data quality depend 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 not been mathematically assessed, according to a preliminary qualitative survey on the reliability of emission factors the main uncertainty proves related to NMVOC, dioxin and PM10 emissions.

Uncertainty on traffic emissions is of particular relevance since road transport is in Lombardy one of the main source of atmospheric emission for CO, PM10, NO_x and NMVOC, and the INEMAR inventory show that a relevant part of traffic emissions is in highly populated areas.
The estimate of road transport emissions may suffer possible uncertainties since emissions depend on several factors (vehicle type, average speed, maintenance conditions) which estimation methodologies consider only with rough approximation. Uncertainty is also 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 yearly non-urban traffic 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.

Figure 4 – NO_x and CO_2 emissions in Linate (LIN) and Malpensa (MXP) airports during a day-type (in Kg h^{-1} unless CO_2 in t h^{-1}).

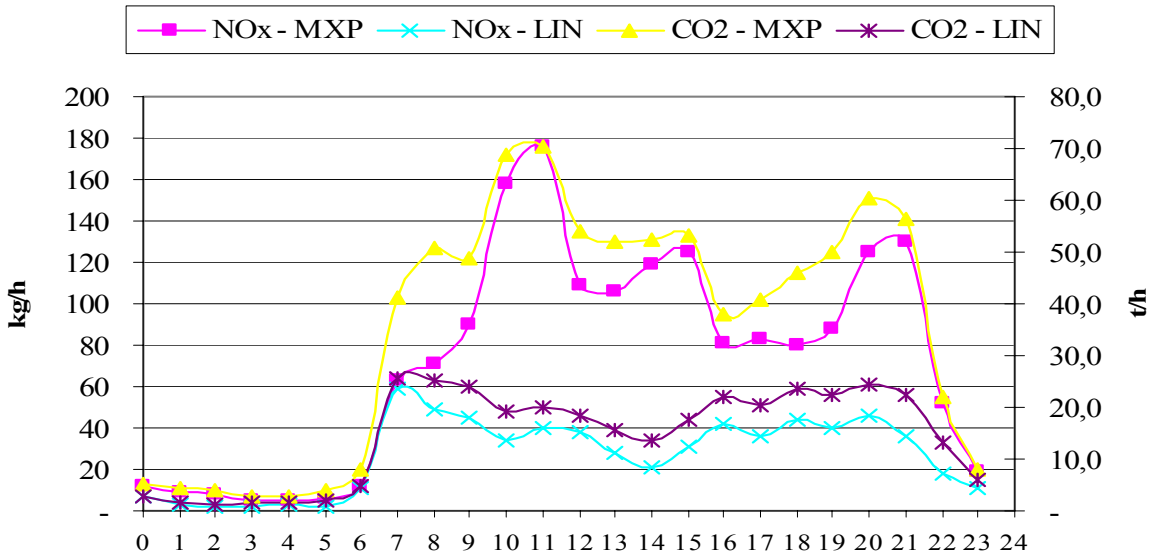


Figure 5 – Landfill emissions by flarings, engines and area sources (in t $year^{-1}$ unless CO_2 in Kt $year^{-1}$).

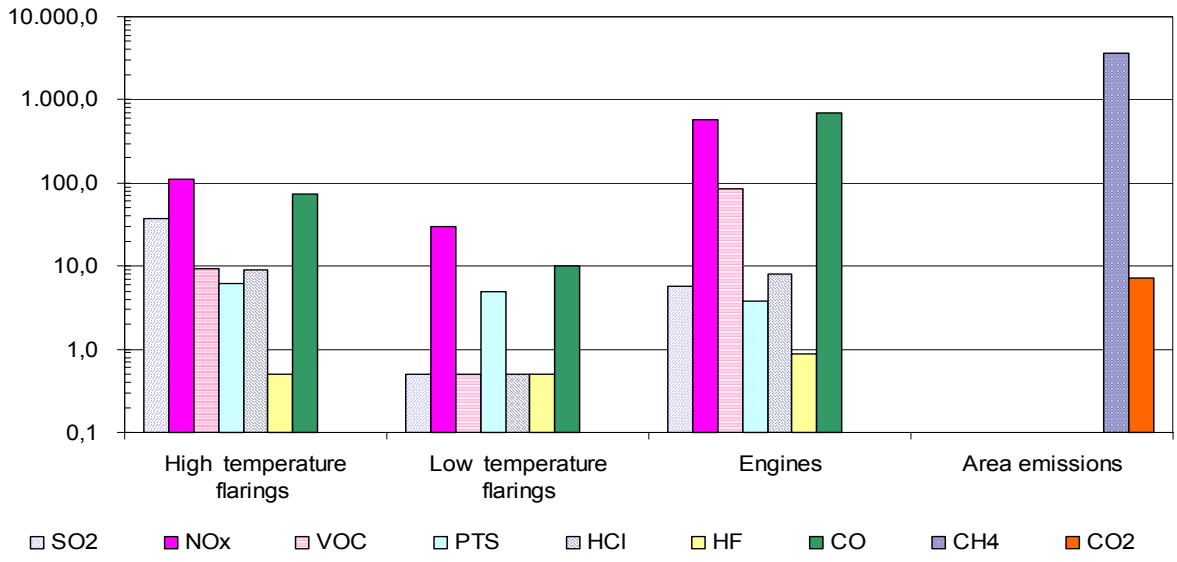


Figure 6 – Emissions in Lombardy Region for 2001 (in t year^{-1} unless CO_2 in kt year^{-1}), shared out for fuel type.

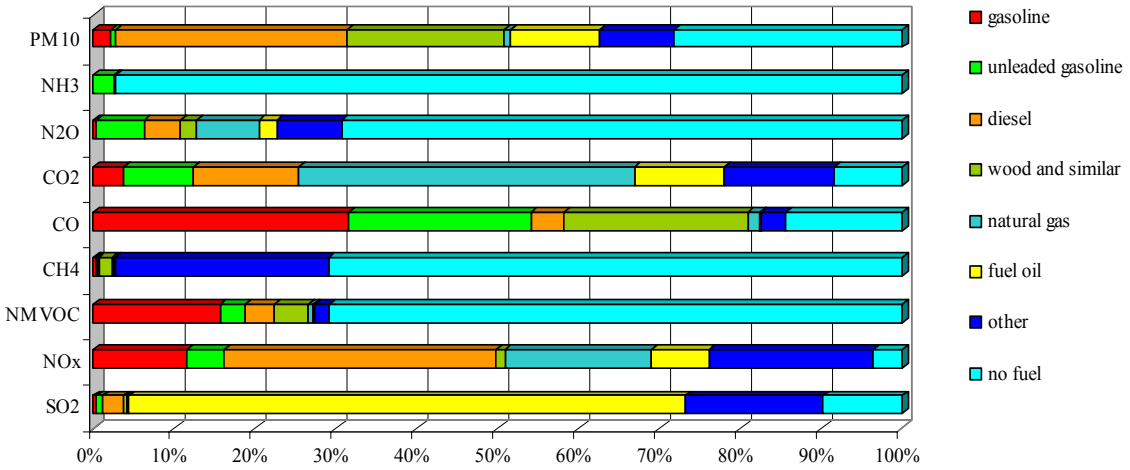
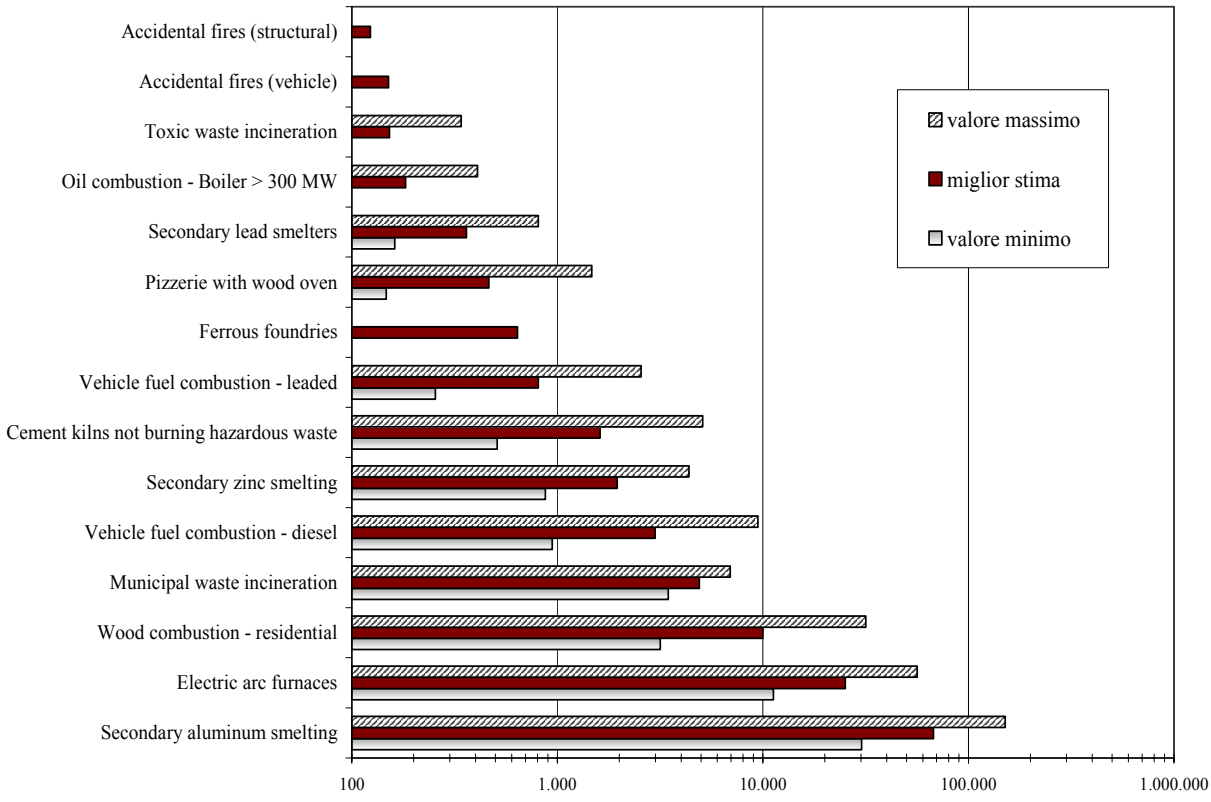


Figure 7 – Minimum, medium and maximum dioxin emissions (mg I-TEQ year^{-1}).



CONCLUSIONS

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 NOx, NMVOC, CO and PM10 for a large number of municipalities over the region.
INEMAR strength can be found in the high resolution (municipality level) of emission results, the great flexibility (Data Base 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.
Besides, INEMAR results are of considerable interest for modeling applications; the covered area (the whole Lombardy region), the high space solution and the wide variety of considered pollutants, from more traditional ones, including ozone precursors (NO_x and NMVOC), to more recently interesting ones, PM10 and PM2.5, represent an important input for primary and secondary air quality modeling.
INEMAR emission data, available to the public at the INEMAR web site page (3) for each pollutant, municipalities, activities and fuel type, have been downloaded by a large number and variety of users since September 2002, and are a base for environmental research and further detailed assessment of emission in Lombardy Region.

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