A detailed Emission Inventory for air quality planning at local scale: the Lombardy (Italy) experience

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ABSTRACT

A detailed atmospheric emission inventory for the Lombardy Region, highly industrialized area of about 9 million inhabitants in the north of Italy, has been realized for the year 2001.

The inventory is based on a database named INEMAR (INventario Emissioni in ARia), and considers about 220 activities and 12 pollutants (SO_2, NO_x, NMVOC, CH_4, CO, CO_2, NH_3, N_2O, TSP, PM10, PM2.5, PCDD/Fs). Emission data for each of the 1546 municipalities of Lombardy, distributed for activities and fuel type, have been available for a public review process at the INEMAR web site page (http://www.ambiente. regione.lombardia.it/inemar/inemarhome.htm).

Different types of sources have been considered. Point sources emissions were calculated by means of a survey of about 250 large plants. Area sources estimates are based on activity indicators and emission factors proposed by EMEP-Corinair Emission Inventory Guidebook, US-EPA Air Chief and other Italian data. Methodologies for agriculture emissions assessment rely on Corinair and IPCC documents. Copert III methodology has been adopted for road transport, with a detailed specification for PM10 based on other European data. Other detailed approaches have been used for the assessment of emissions from biogenic activities, air traffic, tank, landfill. Surrogate variables have been used for the emissions distribution at municipality level.

An accurate analysis has been made for PM10, PM2.5 and dioxin emission factors, in particular with regard to stationary residential combustion.

INEMAR estimates are computed according to both SNAP 97 and IPPC nomenclature. The 2001 emission inventory, that follows the previous 1997 edition, is an essential tool for air quality planning for regional, provincial and municipal authorities in Lombardy and a useful data source largely used by public and private environmental organizations. In addition to ordinary data control, a quality assessment program is in progress.

INTRODUCTION

In the framework of the Regional Air Quality Management Plan (PRQA), a region-wide investigation on air pollution, emissions sources and critical areas' characterization, a detailed atmospheric emission inventory has been set up by the Environmental Department of the Lombardy Region. The 2001 inventory, that updates the first 1997 edition (1), has been concluded in October 2003, and it's now managed by the Air Sector of ARPA, Regional Environmental Protection Agency; data for the main 9 pollutants are available on the INEMAR web page (2) since November 2003 for a public review.

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 a high density of industrial activities (20% of national industry), and hosting specialized industrial districts (textile, wood, metal, silk and knitting), the Region is characterized by a significant development of private transport, with an extremely high use of the personal motor vehicle (a regional average of 76 vehicles every 100 inhabitants, 61 of which cars, and 7 mopeds and motorcycles) (3).

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), TSP, PM10, PM2.5 and dioxins. Although a first inventory of heavy metals (As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn) emissions has been made, the check test phase is still on-going.

Classification of activities

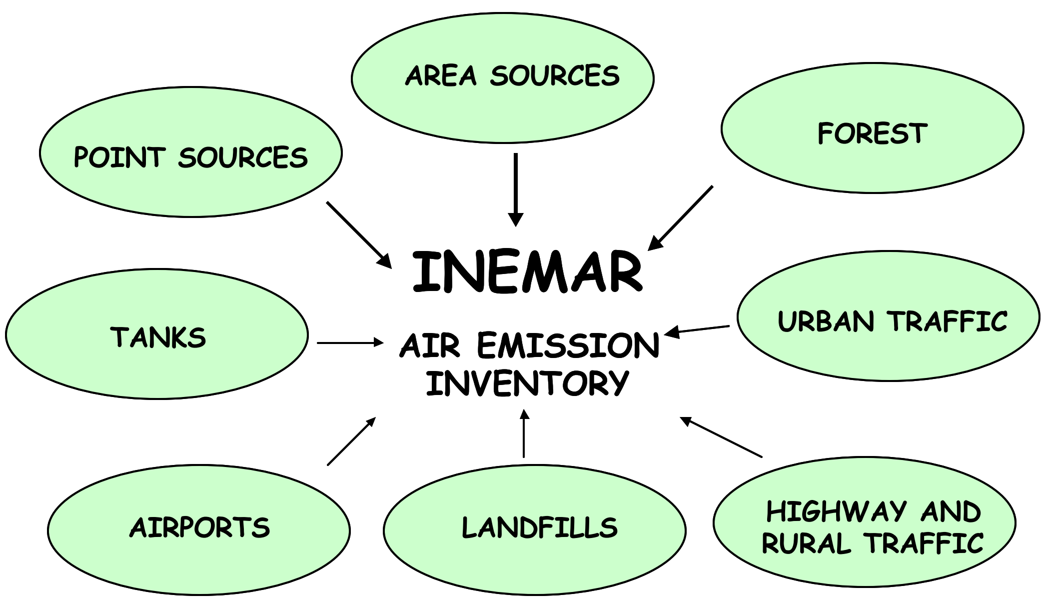
The nomenclature used for the CORINAIR inventory (SNAP - Selected Nomenclature for Air Pollution 97) (4) has been adopted.

The SNAP 97 system is set up according to three levels:

- the upper level - 11 source categories – which features sources' grouping as commonly performed;
- the intermediate level - 75 source sub-categories (48 of which used in the Lombardy Inventory) - comprehending technological and social-economic criteria;
- the lower level - 485 source activities aiming at an exhaustive enumeration of sources and sinks to spot homogeneous sections in generating emissions.

The 220 source activities taken into account in the Lombardy Inventory have been organized according to SNAP hierarchy at lower level. 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 the distribution of a form that had to be filled out by the plant's management. The plants included into the survey 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 from periodic measurements, and are computed basing on specific data of the plant (flue gas concentration, flow rate, temperature, etc.). For other pollutants, specific data of the plant, such as activity rate, number of employees, etc., have been used together with emission factors taken by literature (point – sources) to obtain “estimated emissions".

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 from statistical surveys on provincial and regional scales or from industrial associations data, whereas some detailed data came from survey forms filled in by major industrial plants.

Emission factors used in the 2001 inventory derive from different sources as the 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).

A review of available emission factors has been performed for particulate matter emissions (PM2.5, PM10 and TSP), in particular for residential wood combustion (11) and for dust production in animal husbandry (7, 8, 12, 13).

Traffic emissions

Algorithms proposed by Corinair COPERT III methodology (14) 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 travels along municipal roads.

Data proposed in the last edition of the European Guidebook (15) have been used for non-exhaust PM emissions from road vehicle tyres, brake wear and road surface wear.

An extensive amount of traffic data available in the Lombardy Region covering the period from 1995 to 2001 has 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 daytimes. 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 smaller ones with local traffic and side streets.

Urban traffic emissions have been calculated on the basis 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 basis 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 (16) 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 (5), has been used to assess NMVOC emissions from tanks. Storage and technical characteristics tanks data from chemical and refinery plants as well as marketing depots have been collected.

Emissions from airport traffic have been estimated with the CORINAIR methodology based on landing/take-off cycle data; domestic and international aviation, considering flights number per hour and aircraft categories distinction, have been used for the two main airports in Lombardy (Milano Linate and Malpensa).

Agriculture emissions come from enteric fermentation, manure management in animal husbandry (housing, storage and land spreading) and from fertilized agricultural land for different types of crop. CORINAIR approach (4) has been used in this case as well, and a specific algorithm, for agricultural soils contribution, based on fertilizer type sales, nitrogen crop requirements and agrarian tilled area, has been applied to provide municipal emissions.

The INEMAR database

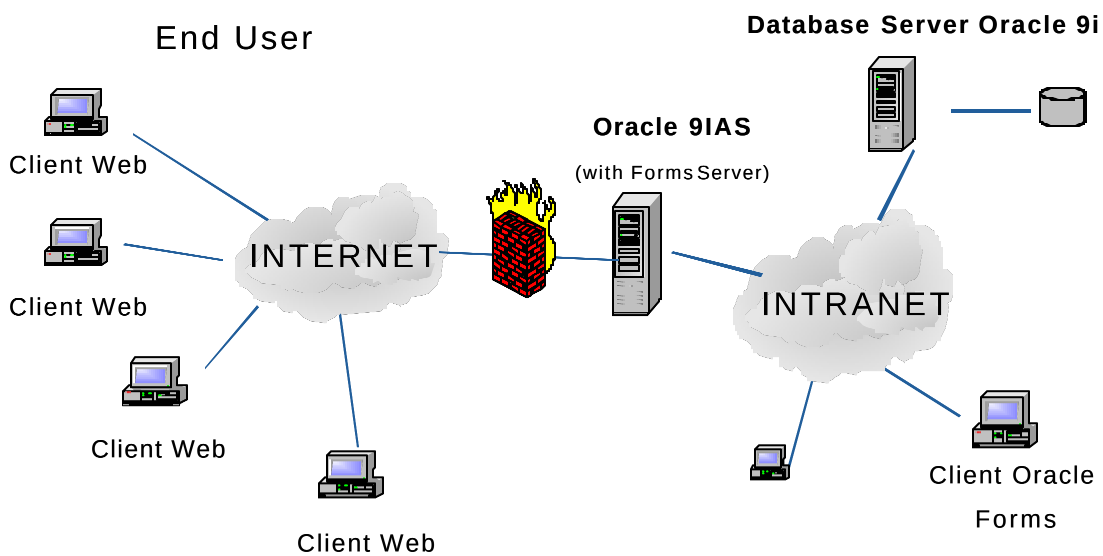
The INEMAR (AiR EMission INventory) database is a multi-user database based on RDBMS Oracle 9i. It contains all data for emission estimates, the procedures to carry out the algorithms used for these estimates and the values of calculated emissions. Algorithms are implemented as packages with Oracle PL/SQL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

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

Emission data are available to the public on the INEMAR web page (2), for each of the 1546 municipalities of Lombardy, with relation to about 220 activities (classified in compliance with SNAP 97 nomenclature), for 15 pollutants and by fuel type.

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 (17).

Figure 2. Physical architecture of INEMAR.



RESULTS AND DISCUSSION

Emissions by pollutant

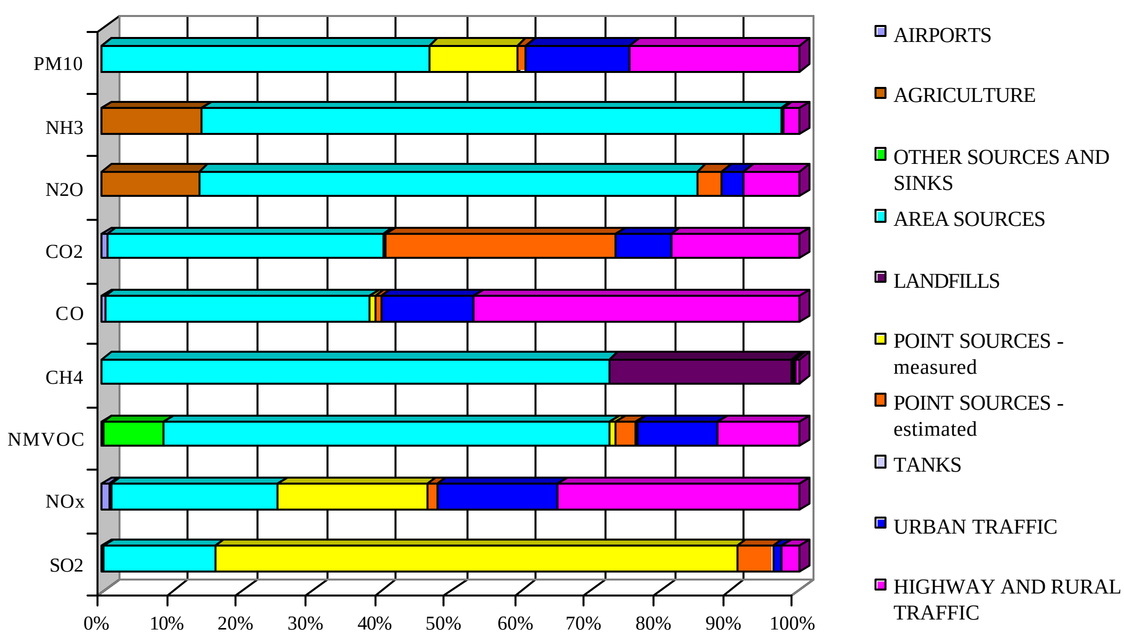
An overview of the emissions for major pollutants and groups of activities (SNAP 97 level 1) is represented in Table 1. Most SO_2 emissions derive from combustion plants in the energy industry

(68% of total SO_2 emissions), whereas NO_x most important source, 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 and PM2.5 emissions, as calculated by the in-depth review of available emission factors, derive mainly from road transport (39% of total PM10 emission), while energy production, residential and industrial combustion processes account for another 40%. Considering different types of INEMAR modules, emissions are generally calculated with area sources methodologies, except SO_2, whose data mostly derive from an assessment based on a declaration by the plants managers (Figure 3).

Table 1. Emissions in Lombardy Region for 2001 ($t\ y^{-1}$ unless CO_2 in $kt\ y^{-1}$ and PCDD/Fs in g TEQ y^{-1}).

	SO_2	NOx	VOC	CH_4	CO	CO_2	N_2O	NH_3	PM10	PM2.5	TSP	PCDD/Fs
1-Combustion in energy and trasformation industries	51.456	26.996	689	710	2.064	16.404	273	1,8	1.450	1.047	1.863	0,3
2-Non-industrial combustion plants	6.244	16.977	13.946	7.720	163.709	16.931	1.837	209	4.733	4.356	5.040	11
3-Combustion in manufacturng industry	10.304	44.554	5.064	1.121	59.114	13.688	743	12	1.846	1.422	2.707	42
4-Production processes	3.524	1.594	30.173	138	24.205	3.890	19	73	2.228	993	2.565	25
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	268	87	318	
7-Road Transport	2.913	114.151	72.704	3.079	434.646	18.794	1.740	2.504	8.480	7.739	9.704	4,1
8-Other mobile sources and machinery	1.202	11.320	1.697	32	5.254	969	246	1,6	85	80	88,7	
9-Waste treatment and disposal	271	1.778	268	116.917	150	813	147	3,7	61	55	64	5,2
10-Agriculture		1.568	1.301	216.520	23.314	0	10.656	94.823	1.182	1.010	1.684	
11-Other sources and sinks	83	364	27.787	5.688	10.477	0	12	83	549	511	578	0,4
Total	**75.998**	**219.610**	**310.957**	**444.069**	**722.935**	**71.490**	**15.672**	**97.728**	**20.883**	**17.300**	**24.611**	**87**

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



Emissions by activities

Considering the SNAP-level 1 classification, in group 1 (combustion in energy and transformation industries) relevant SO_2 emissions derive from residual oil use in combustion plants in energy industries. Emissions in group 2 (non-industrial combustion plants) are generated from natural gas use in the residential sector and wood combustion in fireplaces, stoves, etc..

Combustion in manufacturing industries (group 3) are mainly linked to gas oil and residual oil use in industrial boilers, while emissions of SO_2 are mainly due to bricks/tiles and cement production.

The results obtained in group 4 (production processes) show the contribution of petroleum industry to NMVOC emissions from fuels storage and handling in refineries. CO emissions are mainly due to processes in the metal industry. NMVOC are also emitted by processes in organic chemical industries and by other industries (sugar, animal feed and bread production). Considerable VOC emissions in group 5 (extraction and distribution of fossil fuels) come from the gas distribution network, whereas in group 6 (solvents and other products) high contributions to NMVOC emissions come from painting, from chemical products synthesis and manufacturing, from printing industry and domestic use of solvents.

In group 7 (road transport) non-urban traffic plays the major role among all pollutants emission (65 %), except for NMVOC emitted mainly in urban settlements.

Emissions in group 8 (other mobile sources and machinery) are mainly due to airport operations (Figure 4).

In group 9 (waste treatment and disposal) municipal solid waste incinerators contribute to SO_2, NO_x and NMVOC emissions (63%, 85 % and 82% respectively) whereas CH_4 and CO_2 are generated from landfill activities (Figure 5).

Agriculture (group 10) gives a relevant contribution to CH_4, N_2O and NH_3 emissions in rural areas, whereas in group 11 (other sources and sinks) emissions from forest fires (CO and PM10) and forest (NMVOC) are significant.

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

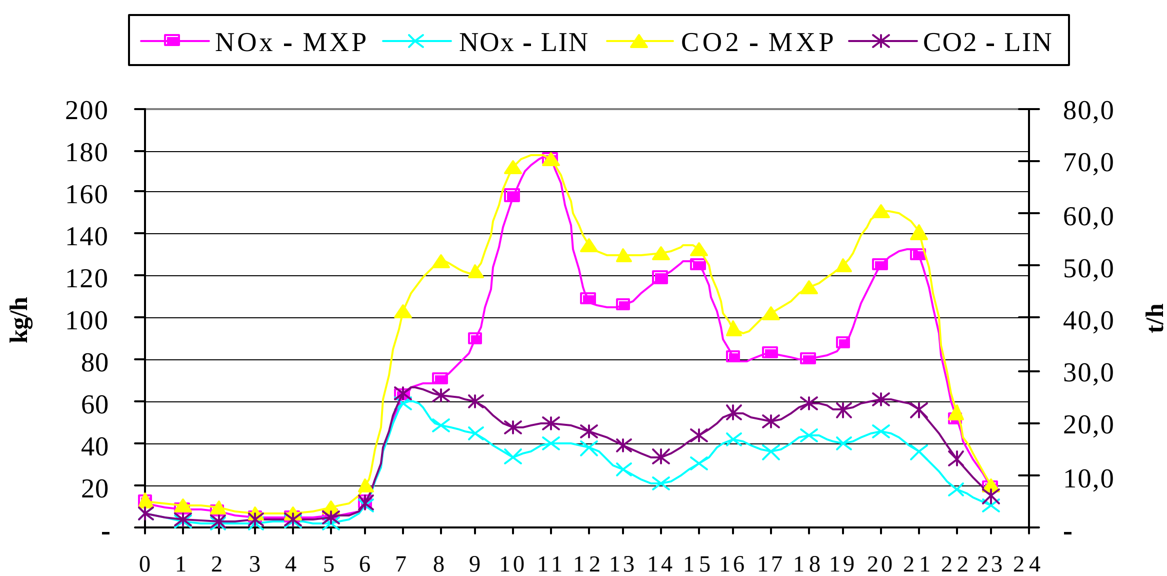
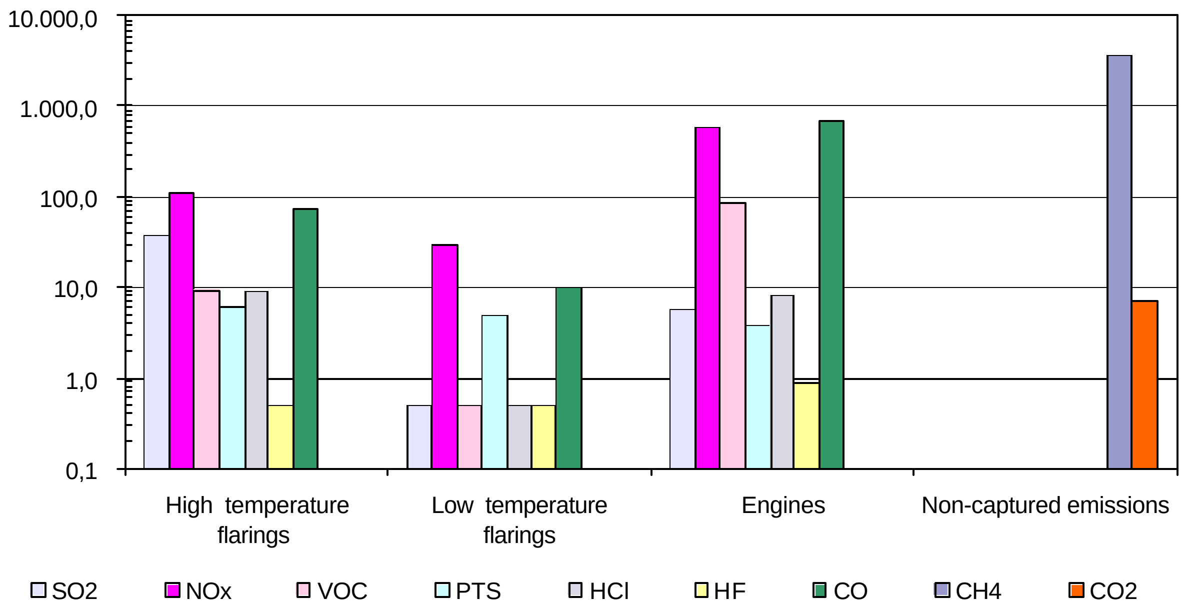


Figure 5. Landfill emissions by flares, engines and non-captured emissions (t y^{-1} unless CO_2 in kt y^{-1}).



Emissions by fuel

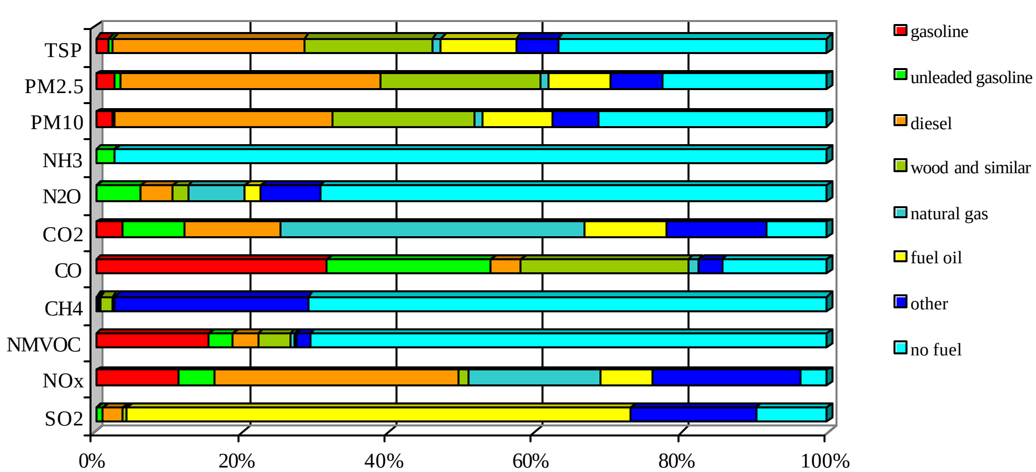
Emissions related to major pollutants and fuels are shown in Figure 6.

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 independent 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.

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

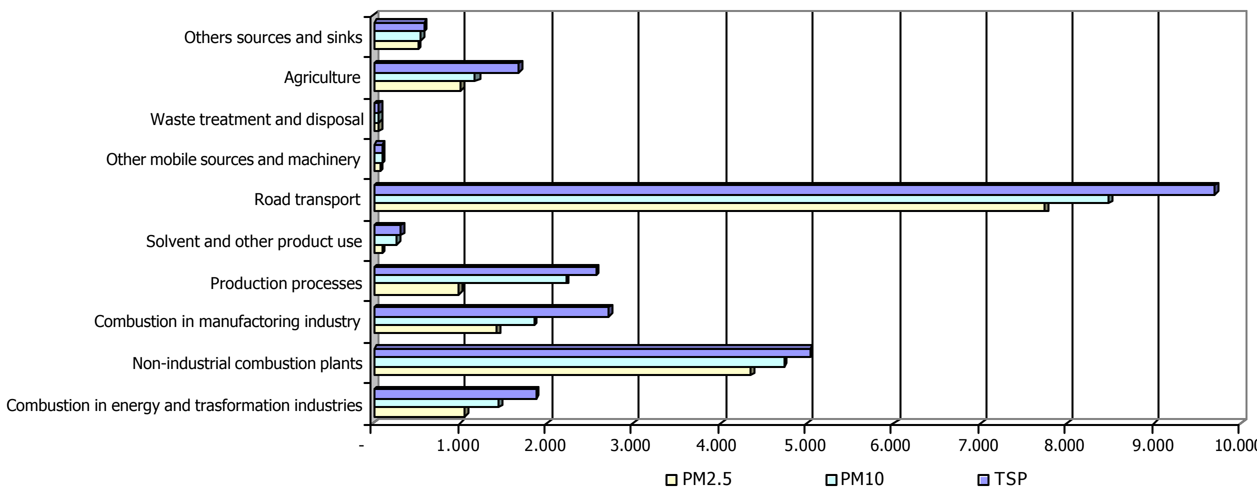


PM10 and PM2.5

Fine particles emissions by groups of activities (SNAP 97 level 1) are shown in Figure 7. The main source of particulate matter in Lombardy Region is road transport, followed by combustion processes, both in domestic and industrial sectors, production processes and agriculture.

As regards fine particles emissions, the main source is again road transport for both PM10 and PM2.5 emissions (39% and 45%, respectively) followed by combustion in domestic and industrial plants: in particular, by fuel type, the most important source of PM10 is wood combustion in residential fireplaces, followed by emissions from diesel vehicles and on-field burning of agricultural wastes.

Figure 7. Particulate matter emissions in Lombardy Region for 2001 (t y^{-1}).



Emissions from agriculture are here related only to the on-field burning of agricultural wastes (stubble, straw,…). Emissions from animal husbandry (dairy cows, other cattle, fattening pigs, sows, laying hens, broilers and other poultry) have been estimated with two sets of emission factors (7, 8) but they have not been taken into account in the final results as further studies are still ongoing (Figure 8).

Dioxin

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, as shown in Figure 9.

Minimum and maximum emission levels have been calculated by means of the US-EPA approach (10), assigning high, medium or low confidence for both the emission factor and the activity term.

This lower overall confidence rating of the two related quality indexes is assigned to an emission estimate, obtained by the product of activity and emission factors. The uncertainty is evident when presenting a central "best guess" and a possible range, whose extension depends on data quality. The best guess estimate is used as a central point of a range determined by treating the central value as a geometric average of the end points (Figure 9).

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. Wood residential combustion, municipal waste incineration and vehicle diesel fuel combustion are the second heavy contributors to regional dioxin emissions, responsible for an average total value of 22%.

Figure 8. Comparison between particulate emissions derived from two different set of emission factors for animal husbandry (t y^{-1}).

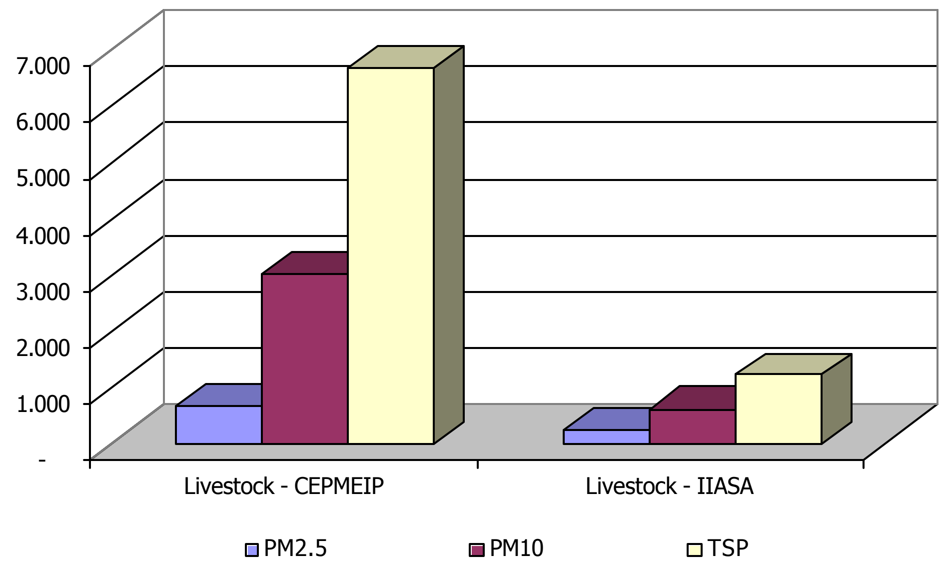
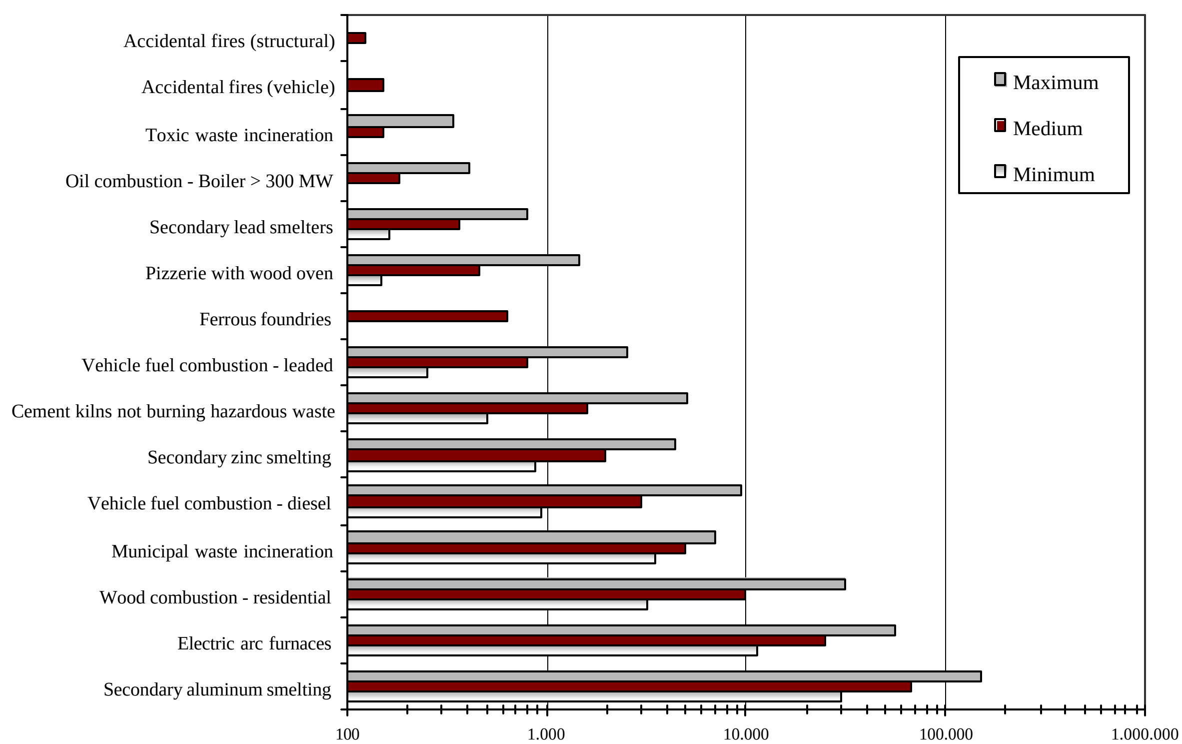


Figure 9. Minimum, medium and maximum dioxin emissions (mg TEQ y^{-1}).



Spatial distribution

Emission data for each pollutant in the single municipality are visualized with the maps of the program Nebula LTK. Figure 10 and 11 show that whereas CH_4 emissions are concentrated in country areas, the highest score of PM10 and NO_x can immediately be noticed in the hinterland of Milan and in other municipalities in the provinces of Pavia, Brescia and Bergamo.

The detail of the emission inventory allows to summarize emissions for different aggregations of municipalities; as an example, the availability of the total emissions in the “critical areas” of Lombardy, as defined within the Regional Plan for Air Quality, is of particular interest for the definition of an intervention strategy for air quality improvement in areas most affected by air pollution.

Emissions uncertainty

Continuous emissions data, as well as data assessed by the emission inventory are subject to uncertainties. While monitoring systems reliability and data quality depend on the 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 polluting emissions has not been mathematically assessed, according to a preliminary qualitative survey on the reliability of emission factors, the main uncertainty proves to be related to NMVOC, dioxin and PM10 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 the most critical methodologies for sources assessment have therefore been scheduled to achieve an efficient management of air quality.

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 NO_x, NMVOC, CO and PM10 for a large number of municipalities in 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 modelling 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 pollutant of more recent interest, like PM10 and PM2.5, represent an important input for primary and secondary air quality modelling.

As an example, PM10 emissions in the Great Milan area (Figure 12) have been used for a modelling simulation. The model FARM (Flexible Air quality Regional Model), an eulerian three-dimensional photochemical and transport model, has been applied over a 70 x 70 km^2 domain with a of 1 km grid size (18) by ARIANET s.r.l. for IRER and Regione Lombardia in collaboration with ARPA.

An emission pre-processor has been developed and applied to manage INEMAR dbase and all the profiles (emission source chemical speciation and temporal profiles, spatial surrogate variables) necessary to prepare emission input into the detail and format required by FARM and into the VOC and PM lumped classes according to the chemical mechanism and particulate module implemented in the model.

Figure 10. NO_x emission density in Lombardy (t y^{-1} km^{-2}).

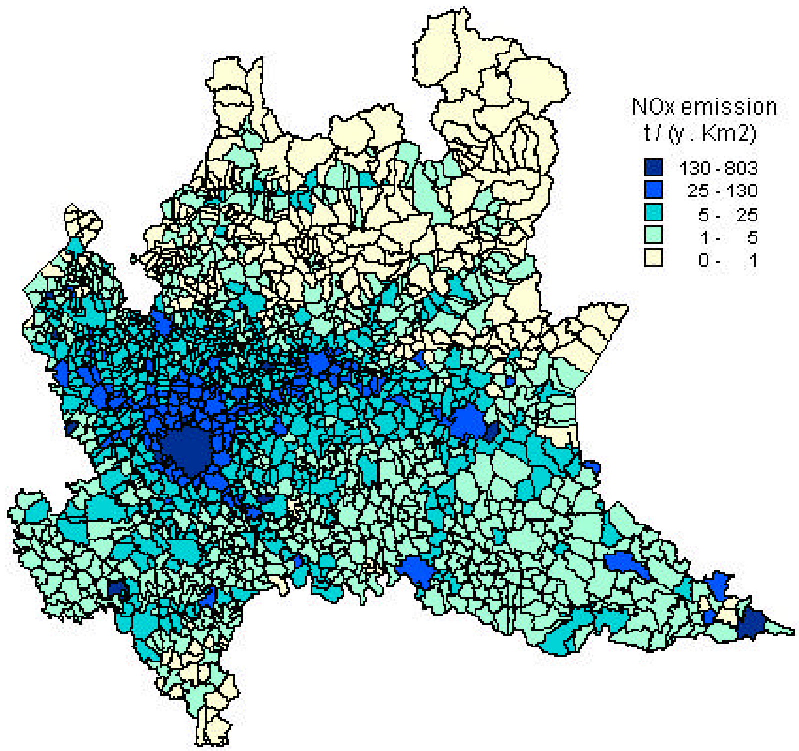
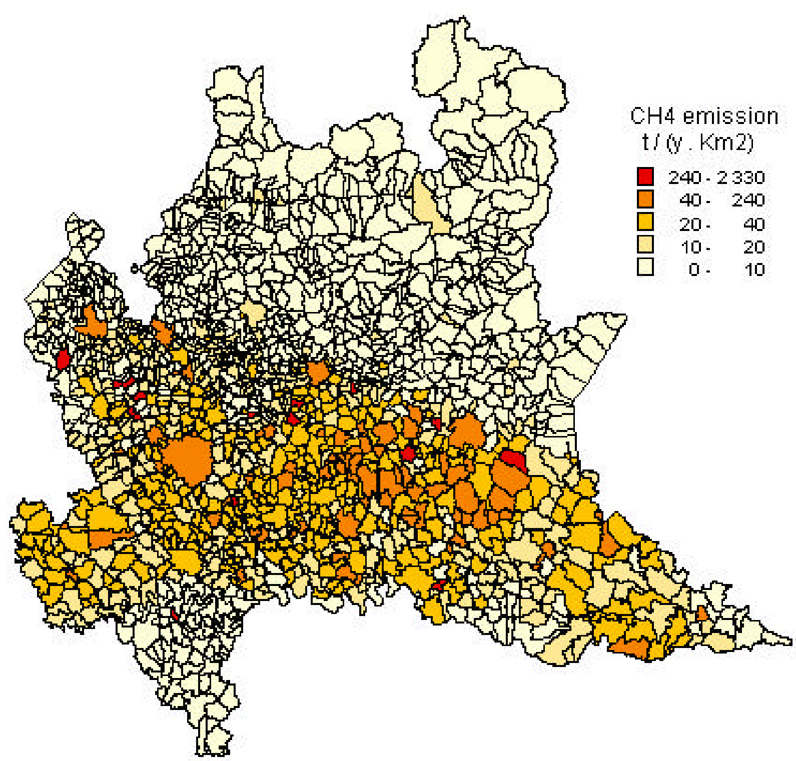
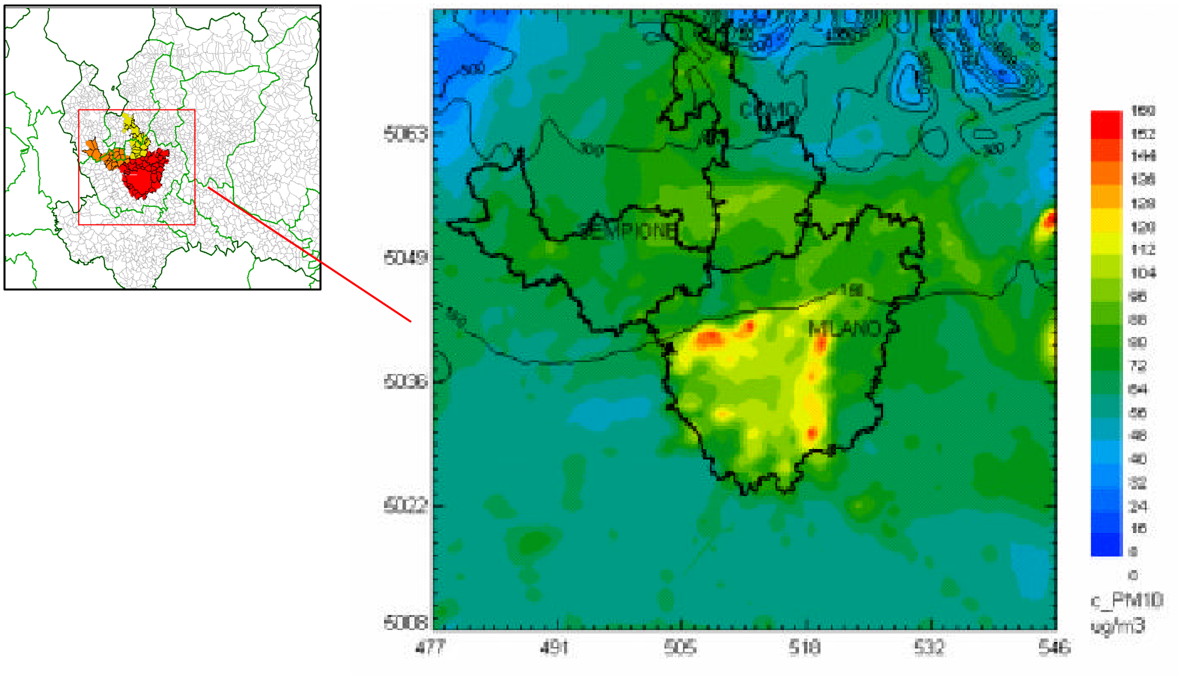


Figure 11. CH_4 emission density in Lombardy (t y^{-1} km^{-2}).



INEMAR emission data, available to the public at the INEMAR web site page (2) 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 basis for environmental research and further detailed assessment of emissions in Lombardy Region.

Figure 12. Modeling simulation of PM10 ground-level concentration in the Milano area on Dec. 18, 2001 at 9.00 h



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KEYWORDS Emission inventory, Italy, Lombardy Region, PM10, database.