

Emissions estimate from forest fires: methodology, software and European case studies

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ABSTRACT

In the paper first a complete methodology for the estimate of air pollutant emissions from forest fire will be presented. Next a specific model and a computer code for the estimate of emissions will be introduced. Finally a lot of case studies will be discussed.

The methodology for estimate emissions from forest fires was developed on the basis of the information from EMEP/CORINAIR Task Force on Emission Inventories and, for Particulate Matter with diameter inferior to 10 microns, United States Environmental Protection Agency.

The model, Air Fire, allows the estimate of the emissions produced by forest fires. The model is developed in Windows environment with object-oriented Visual Basic language and is available with an ACCESS database.

A lot of case studies will be presented. The model has been used at a national level (for the realization of a national emissions inventory) and at regional level (in the frame of emissions inventories and air quality management plans). At national level in Italy forest fires can contribute up to 4.5% of Carbon Monoxide and up to 1% of Nitrogen Oxides and Carbon Dioxide emissions while, at regional level, forest fires can be up to 5% of Carbon Monoxide and up to 8% of Particulate Matter with diameter inferior to 10 microns emissions.

INTRODUCTION

In the paper first a complete methodology for the estimate of air pollutant emissions from forest fire will be presented. Next a specific model and a computer code for the estimate of emissions will be introduced. Finally a lot of case studies will be discussed.

The methodology for estimate emissions from forest fires was developed on the basis of the EMEP/CORINAIR Task Force on Emission Inventories and, for PM₁₀, United States Environmental Protection Agency indication. The methodology estimates emissions from the surface of different tree species burned, and evaluation of effective burned biomass. In the methodology the emissions are estimated starting from surface of different tree species fired, with the following steps:

- evaluation of effective fired biomass (through evaluation of fired forest area, evaluation of above surface biomass factor, evaluation of forest fire efficiency),
- evaluation of total Carbon, total Nitrogen and total Particulate Matter emitted,
- carbon compounds, nitrogen compounds and PM₁₀ emissions evaluation.

The air pollutants considered are: Carbon Monoxide (CO), Carbon Dioxide (CO₂), Methane (CH₄), Nitrogen Oxides (NO_x), Nitrogen Protoxide (N₂O), Particulate Matter with diameter inferior to 10 microns (PM₁₀).

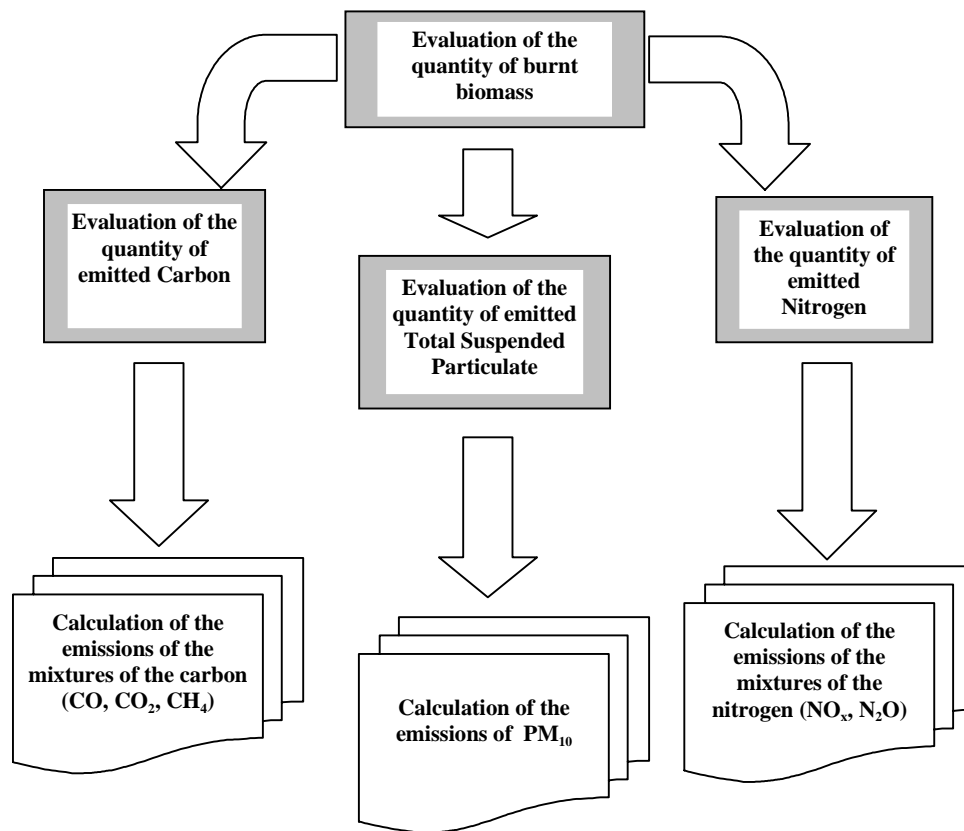
METHODOLOGY

The emissions estimate follows the methodology developed by EMEP/CORINAIR Task Force on Emission Inventories¹ integrated with the methodology of the United States Environmental Protection Agency² (USEPA) with reference to the PM₁₀. For this last pollutant a procedure consistent with the preceding ones has been introduced to the goal to furnish only one computational methodology.

Particularly for the calculation the followings steps will be followed (Figure 1):

- evaluation of the quantity of burnt biomass;
- evaluation of the quantity of emitted carbon;
- evaluation of the quantity of emitted nitrogen;
- evaluation of the quantity of emitted total particulate;
- calculation of the emissions of the mixtures of the carbon (Carbon Monoxide, Carbon Dioxide, Methane);
- calculation of the emissions of the mixtures of the nitrogen (Nitrogen Oxides, Nitrogen Protoxide);
- calculation of the emissions of Particulate Matter with diameter less than 10 micron.

Figure 1. Emissions estimate data flow



Evaluation of the quantity of burnt biomass

The quantity of dry biomass of given vegetation specie burnt is given from:

$$M_i = \alpha A_i B_i$$

where:

- i vegetation specie,
- A_i area (in hectares) of fired surface covered by the i specie,
- B_i middle quantity to dry biomass (in tons for hectare) emerged by the ground for i specie,
- α efficiency of the fire or fraction of definitely destroyed biomass (in case of complete fire must be sets equal to 1 while in case of partial fire it will have to express the evaluation of the quantity of biomass indeed burnt).

In the model are takings in consideration the different crops as defined by the forest statistics. The list of the crops is brought in Table 1 together with an approximate evaluation of the middle quantity of biomass emerged by the ground for every crop.

Table 1. List of the crops and relative biomass emerged by the ground.

Crops	Biomass (t/ha)
Resinous tall stem	295
Deciduous tall stem	250
Mixed tall stem	225
Simplex coppice	175
Mixed coppice	185
Mediterranean bush	50

Evaluation of the quantity of emitted carbon

The quantity of emitted carbon (in tons) is given from:

$$C = \beta M$$

where β is the carbon's quantity contained in the biomass (can be set equal to 0.45). The quantity remainder of biomass is mainly constituted by hydrogen and oxygen.

Evaluation of the quantity of emitted nitrogen

The quantity of emitted nitrogen (in tons) is given from:

$$N = \gamma' C = \gamma M$$

where γ' is the proportion among emitted carbon and nitrogen (can be set equal to 0.01) and γ the nitrogen quantity contained in the biomass (can be set equal to 0.0045).

Evaluation of the quantity of emitted total particulate

The quantity of emitted total particulate (in tons) is given from:

$$P = \delta M$$

where δ is the quantity of total particulate emitted for unity of biomass (in g of total particulate emitted for g of burnt biomass). As it regards such quantity it is used the datum USEPA of 0.0085.

Calculation of carbon compounds emissions

The emissions (in tons) of carbon compounds (Carbon Monoxide, Carbon Dioxide, and Methane) are obtained as:

$$E_j = \varepsilon_j \delta_j C$$

where j is the compound, ε_j is the fraction of total carbon emitted as compound j ; δ_j is the factor of passage from the emissions in tons of Carbon to the emissions in tons of the specific compound.

In Table 2 are brought the fraction of total carbon emitted as composed j and the factor of passage by the emissions in tons of Carbon to the emissions in tons of the specific pollutant.

Table 2. Factors for the calculation of the emissions of Carbon compounds.

<i>Compound</i>	<i>Fraction of total carbon emitted as</i>	<i>Conversion factor from C mass to compound mass</i>
Carbon Dioxide	0,888	44/12
Methane	0,012	16/12
Carbon Monoxide	0,1	28/12

Calculation of nitrogen compounds emissions

The emissions (in tons) of nitrogen compounds (Nitrogen Oxides, Nitrogen Protoxide) are obtained as:

$$E_j = \varepsilon_j \delta_j N$$

where j is the compound, ε_j is the fraction of total nitrogen emitted as composed j; δ_j is the factor of passage from the emissions in tons of Nitrogen to the emissions in tons of the specific compound.

In Table 3 are brought the fraction of total nitrogen emitted as compound j and the factor of passage by the emissions in tons of Nitrogen to the emissions in tons of the specific pollutant.

Table 3. Factors for the calculation of the emissions of Nitrogen compounds.

<i>Compound</i>	<i>Fraction of total nitrogen emitted as</i>	<i>Conversion factor from N mass to compound mass</i>
Nitrogen Oxides	0,007	44/28
Nitrogen Protoxide	0.012	30/14

Calculation of Particulate Matter emissions

As it regards the emissions of Particulate Matter with diameter inferior to 10 microns, for coherence with the preceding cases, the emissions (in tons) are obtained as:

$$E_j = \varepsilon_j N$$

where j is the fraction of Total Suspended Particulate with diameter inferior to 10 microns, ε_j is the fraction of total particulate emitted as fraction j.

In Table 4 are brought the fraction of Total Suspended Particulate emitted as Particulate Matter with diameter inferior to 10 microns (datum USEPA).

Table 4. Factors for the calculation of the emissions of Particulate Matter with diameter inferior to 10 microns.

<i>Compound</i>	<i>Fraction of Total Suspended Particulate emitted as</i>
Particulate Matter with diameter inferior to 10 microns	0,73

SOFTWARE

The model Air Fire allows the estimate of the emissions produced by forest fires.

The model is part of a complete system for air pollution evaluation (Air Suite) containing tools for emissions inventory (APEX), models to estimate emissions in particular topics (road transport, airports, forests, ports and navigation lines, forest fires), a model for projection of emissions and to evaluate measures on emissions, an air quality monitoring and meteorological data base, a land use geographical

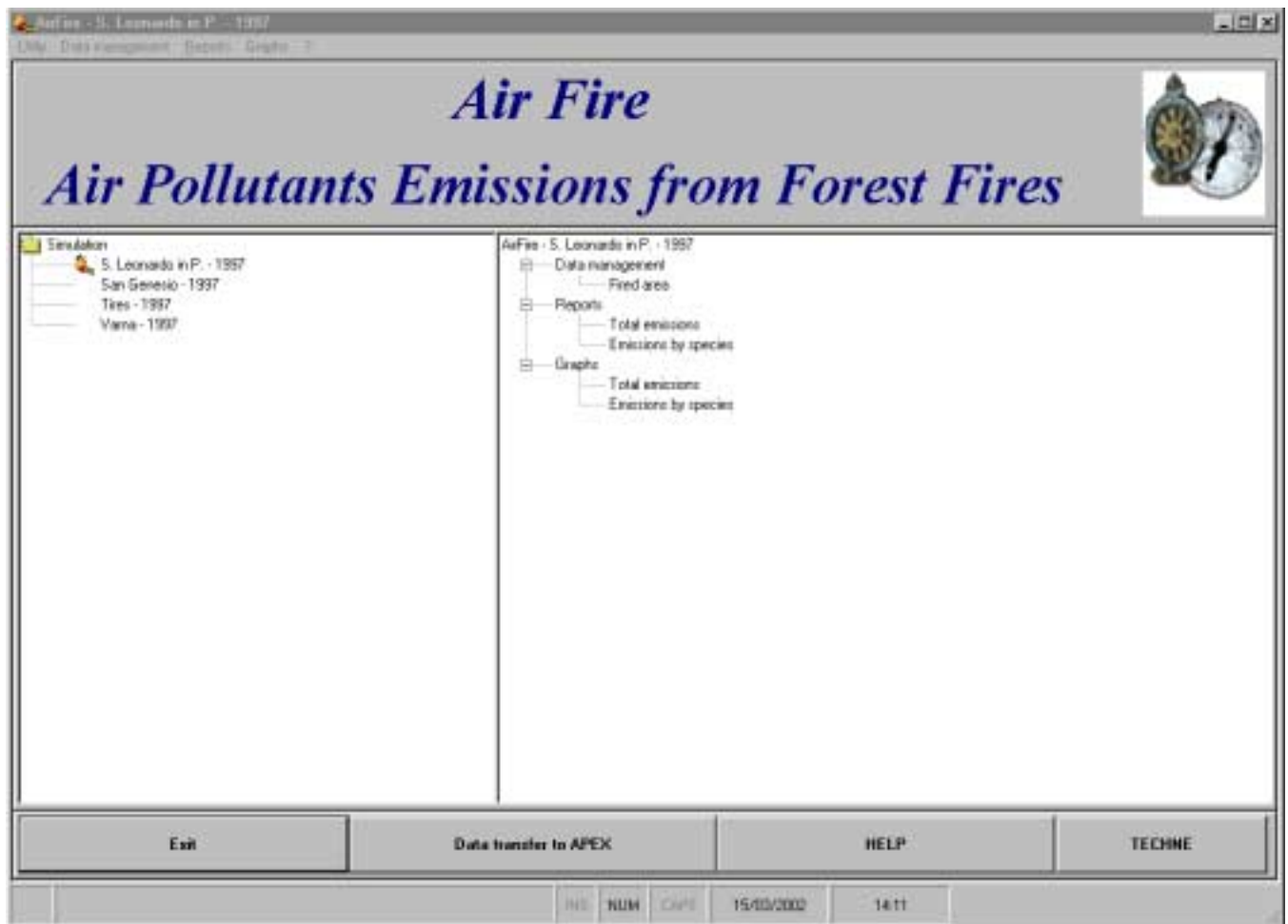
information system, a statistical package for air quality and meteorological data analysis, air quality dispersion and photochemical models, and geographical information systems.

The model is developed in Windows environment with object-oriented Visual Basic language and is available with an ACCESS database.

An application in the model environment is called simulation and each model consists in a lot of simulation. A simulation regards a geographical domain (area) and a temporal domain (year, month, day, and hour). The results of the models can be transferred to APEX (Air Pollutant Emissions Computer System) for regional integrated emission evaluation.

In Figure 2 the main menu of the software is reported.

Figure 2. Air Fire main menu.



The following model menus are presented to the user:

- utility
- data management
- reports
- graphs.

The *utility* function has the following options:

- simulation management
- make an existing simulation on line
- create a new simulation
- modify an existing simulation
- deleting an existing simulation

- export of simulation data to APEX.
The *data management* function has the following options:
- manage of *fired area* (allows to insert or modify fired area).
The *reports* function has the following options:
- report of *total emissions* (produce the report of the total emissions for all pollutants);
- report of *emissions by species* (produce the report of the total emissions for all pollutants and each crop species).
The *graphs* function has the following options:
- graph of *total emissions* (produce the graph of the total emissions for all pollutants);
- graph of *emissions by species* (produce the graph of the total emissions for all pollutants and each crop species).

CASE STUDIES

The model was used at a national level (for the realization of a national emissions inventory) and at regional level (in the frame of emissions inventories and air quality management plans).

At regional level, the methodology and the computer model were used in the realization of several regional air quality management plans in Italy³ (Trento, Toscana, Bolzano, Liguria, Friuli Venezia Giulia and Umbria regions) and several emissions inventories (Firenze, L'Aquila, Roma).

National Case Study Results

The emissions estimate uses the official statistical data available from Forest Body of the State. The Forest Body of the State, since the years 70, picks up and elaborates the information and the data on the forest fires that occur during the year, through the compilation of a model denominated AIB/FN-Sheet. Recently (1997) the model has been updated to adjust it to the new legislations that discipline the forest subject and to the development of the techniques of prevention and struggle. Has been activated, besides, an informative system that, using the actual computer technologies, allows the networking among the peripheral offices of the Forest Body of the State, in charge to collect and elaborate data, the Service "*Forest Fire Struggle*" of General Direction and the Office of Statistic. This allows to update a real time data base and to have univocal data on the forest fires to central level.

Detailed emissions estimate obtained from Forest Body of the State data, using the model described in the paper, are reported in Table 5 for 1998. All the simulations use an average efficiency of the fire (or fraction of definitely destroyed biomass) $\alpha = 0.2$. The work was partially performed in the framework of Techne - Ministry of the environment convention for "Evaluation of the entity and the effects of the reduction of the emissions of pollutants ruled by international protocols".

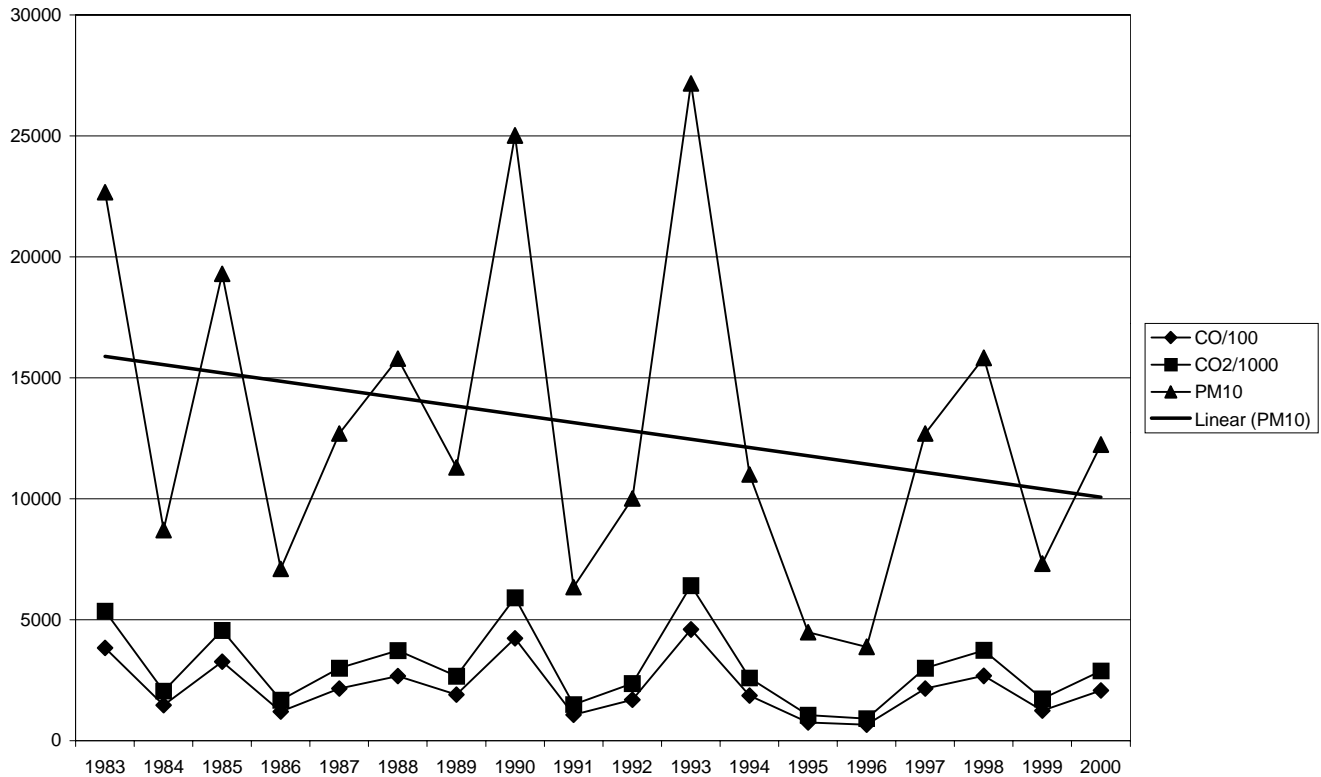
Table 5. National forest fires emissions estimate – year 1998 (tons).

Species	CH ₄	CO	CO ₂	N ₂ O	NO _x	PM ₁₀
1 - Resinous	5772.9	84187.6	1174778.3	92.8	39.7	4975.1
2 - Deciduous	3054.0	44537.3	621485.8	49.1	21.0	2631.9
3 - Mixed Resinous/Deciduous	4134.5	60294.1	841361.4	66.4	28.4	3563.1
4 - Simplex coppice	4457.0	64997.3	906990.9	71.6	30.6	3841.0
5 - Mixed coppice	325.2	4742.9	66183.6	5.2	2.2	280.3
6 - Coppice deteriorate	874.9	12758.3	178033.2	14.1	6.0	754.0
7 - Mediterranean bush	1096.3	15987.8	223098.4	17.6	7.5	944.8
TOTAL	19714.8	287505.3	4011931.6	316.8	135.5	16990.2

An evaluation of the contribution of emissions from forest fires (Table 5) on total national emissions can be obtained using the national official total emissions estimates by the Italy Environmental Protection Agency (ANPA)⁴. From these data it is obtained that the forest fires contribute for about 4.5% to the national Carbon Monoxide emissions, 1% to the national Nitrogen Oxides and Methane emissions, 0,9% to the national Carbon Dioxide (CO₂) emissions and 0,2% to the national Nitrogen Protoxide emissions.

In Figure 3 for PM₁₀, CO₂ and CO summary results are reported from 1983 to 2000 [Mediterranean bush excluded]. The results show a reduction in emissions during the years.

Figure 3. Italy 1990-1995 forest fires PM₁₀ (tons), CO₂ (ktons) and CO (tons * 10) emissions [*].



[*] Mediterranean bush excluded, 2000 preliminary data

Regional Case Study Results

The nomenclature used in the emissions inventories, at the local level in Italy, follows the European Commission CORINAIR working group guidelines. CORINAIR nomenclature includes about 200 activities grouped in 11 groups adapted for local inventories.

The pollutants included in the inventories are:

- five main air pollutants, namely Nitrogen Oxides (NO, NO₂, N₂O), Sulphur Oxides (SO₂, SO₃), non-methane Volatile Organic Compounds (VOC), Carbon Monoxide (CO) and Particulate Matter with diameter less than 10 μ (PM₁₀); regarding VOC, the speciation of emissions has been sometimes considered for using photochemical models;
- heavy metals (As, Cd, Cu, Cr, Hg, Pb, Zn);
- greenhouses gases: Carbon Dioxide (CO₂), Methane (CH₄) and Nitrogen Protoxide (N₂O);
- ammonia (NH₃).

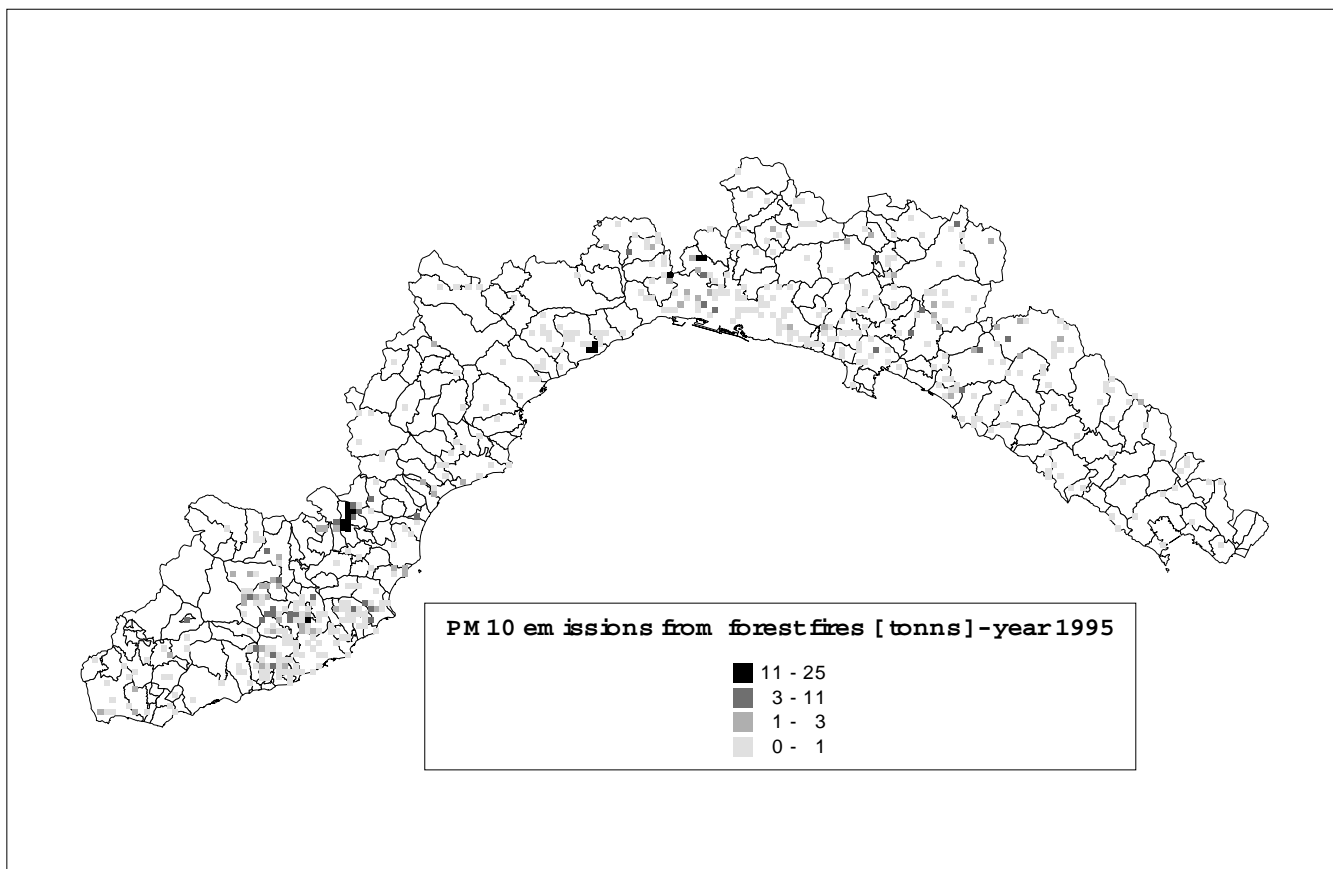
Some experiences of air toxics emissions inventories were realized at local level while, in current inventory activities, benzene and polycyclic aromatic hydrocarbons (PAHPs) are introduced.

The sources are generally split in three categories: *point sources*, *area sources* and *linear sources*.

Plant emissions authorizations are used, for industrial area sources, to evaluate the emissions and to allocate them on a square grid mesh (1km x 1km). Other area sources (for instance, domestic solvent use and natural sources) are evaluated on a geographical basis, inside each municipality and subsequently spatially disaggregate on a square grid mesh. These sources are characterized using statistical or survey data on suitable indicators (for example: paint consumption, fuel consumption, population) and emission factors. In the absence of specific indicators, it is possible to use surrogate variables that, because of their high correlation with the activity, allow obtaining almost reliable results. The emissions factors can be found in literature.

For forest fires the data from Forest Body of the State are used. In Figure 4 an example, using data from Liguria Regional Coordination of Forest Body of the State, is reported on 1 km x 1 km grid base.

Figure 4. Liguria 1995 forest fires PM₁₀ emissions.



At regional level, in Liguria in the year 1995, forest fires emissions were 5% of total CO emissions and 8% of total PM₁₀ emissions.

CONCLUSIONS

In the paper methodology and software for forest fires emissions estimate are presented. The methodology and the software can be usefully applied to national and local emissions estimates.

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