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Emission Uncertainties Evaluation in Air Pollutants Emission Inventory Computer System

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ABSTRACT

In the paper methodology and software tool for evaluate emissions uncertainties in emission inventory at regional level are presented. During the last years in Italy emission inventories were developed at different geographical level (national, regional, local). The paper resume the methodology followed for regional emission inventory realization in Italy and reports the methodology followed in a first case study to evaluate overall uncertainties for such an inventory. For the case study, the general methodology for uncertainties evaluation proposed by EPA EIIP and referred as DARS has been used. In the paper discuss as the methodology DARS has been personalized to the goals of a greater correspondence to the territorial reality that the regional inventory wants to represent. Next the integration of the methodology in the Air Pollutant Emission Inventory Computer System (APEX) is discussed. APEX is part of a complete system for air pollution evaluation (Air Suite) containing tools for emissions inventory, 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, air quality monitoring and meteorological data base, land use geographical information system, statistical package for air quality and meteorological data analysis, air quality dispersion and photochemical models, and geographical information systems. The system was broadly used in the last years in Italy at regional and local level.

INTRODUCTION

In the last years a growing relevance in the emission inventory area is played by uncertainty. In the paper the methodology used for emission inventory preparation at local level is first resumed. The inventory introduces point, linear/nodal and diffuse sources. The fixed sources, for which the total annual emissions of one pollutant are larger than an upper (lower) fixed threshold value, were considered main (minor) point sources. Linear/nodal sources correspond to the main communication ways (road, river, railway, and seaway): all highways, main extra-urban roads, ports and airports are included. All the other sources are defined as area sources.

Numeric factors for emissions uncertainties of the different class of emissions sources are introduced as from the point of view of level of activities as from the point of view of the emissions factors. An appropriate algorithm for emissions uncertainties evaluation starting from activities data uncertainties and emissions factors uncertainties are discussed. Finally, algorithms for uncertainties propagation from single sources category emissions estimates to group sources categories emissions estimates are introduced.

The emissions inventory computer system 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, air quality monitoring and meteorological data base, land use geographical information system, statistical package for air quality and meteorological data analysis, air quality dispersion and photochemical models, and geographical information systems. The system is developed in Windows environment with object-oriented Visual Basic language and is available with ORACLE, SQLServer or ACCESS database. In the paper the specific computer module to evaluate emissions inventories uncertainties will be described.

Finally a case study will be presented. The system was used at regional level in the frame of emissions inventories implementation.

EMISSIONS INVENTORY

The emissions inventory activity in Italy started in 1980 at a national level[1] and has been applied at the local level since 1990[2]. The preparation of air pollutants emissions inventories allows characterization of the different role played by the various emission sources and consequently represents a basic tool to define criteria for air quality management plans[3]. A recent paper reports a balance of air quality management activities in Italy[4].

The nomenclature used at the local level follows the guidelines of the European Commission CORINAIR working group[5]. CORINAIR nomenclature includes about 200 activities grouped in 11 groups:

- Combustion in energy and transformation industries (stationary source),
- Non-industrial combustion plants (stationary sources),
- Combustion in manufacturing industry (stationary sources),
- Production processes (stationary sources),
- Extraction and distribution of fossil fuels and geothermal energy,
- Solvent and other product use,
- Road transport,
- Other mobile sources and machinery,
- Waste treatment and disposal,
- Agriculture,
- Other sources and sinks.

The sources are generally split in four categories: main point sources, minor point sources, area sources and linear/nodal sources. The fixed sources, for which the total annual emission of one pollutant is larger than a fixed threshold value, are considered main or minor point sources. Linear/nodal sources correspond to the main communication ways (roads, rivers, railways, and seaways) and nodes (ports, airports) and generally all the highways, all the main extra-urban roads and all the main ports and airports are included. All the other sources are defined as area sources.

For main point sources, information is gathered through a questionnaire that allows collection of general data (identification, location, etc.), structural data (stacks and units characteristics) and quantitative data (pollutant concentrations at the stacks, pollutant emissions, actual production, fuel consumptions). For minor point sources information is gathered through a simplified questionnaire with general data, pollutant emissions, actual production and fuel consumptions.

Area sources (for instance, domestic solvent use and natural sources) are evaluated on a geographical basis, inside each municipal administrative unit, using statistical or survey data on suitable activity indicators (for example: paint consumptions, fuel consumptions) and emission factors.

UNCERTAINTY IN EMISSIONS INVENTORY

Methodology

In the last year very importance was devoted at the determination and evaluation of the uncertainty in emission estimates[6,7,8] and at the methodology available to do this. The goal is always to reduce uncertainty but the contest can be different. Different is the goal of evaluate uncertainty in specific estimate (for examples for a point source) or sector estimate (traffic, vegetation, forest fires) from the evaluation in a national or regional inventory.

As remembered in EIIP program[6], in a national or regional inventory to identify and rank the relative importance of sources of a specific air pollutant may not be as concerned with the uncertainty of specific estimates. This is especially true for smaller emissions sources. If an estimate is highly uncertain, but at worst represents only 1 percent of all the emissions, accurately quantifying the uncertainty is probably not a high priority. However, a source that is insignificant at a national level can be very important at a local level. When viewed from the local community's perspective, high uncertainty in the estimated emissions may be unacceptable.

In the following we use the general methodology proposed by EPA EIIP and referred as DARS. The methodology was resumed in Table 1.

Table 1 - DARS scoring box

Attribute	Factor	Activity	Emissions
Measurement/Method	e_1	a_1	$e_1 * a_1$
Source Specificity	e_2	a_2	$e_2 * a_2$
Spatial Congruity	e_3	a_3	$e_3 * a_3$
Temporal Congruity	e_4	a_4	$e_4 * a_4$
Composite			$[\Sigma_{i=1,4} (e_i * a_i)] / 4$

As uncertainty is assigned to the single activities of the inventory, global uncertainty of group of activities or of the whole inventory can be computed as:

$$I_{ik} = (\Sigma_{j\in k} E_{ij} I_{ij}) / (\Sigma_{j\in k} E_{ij}) \quad (1)$$

where: I_{ik}, uncertainty of the emission of pollutant i from the group k,
I_{ij}, uncertainty of the emission of pollutant i from the single activity j belonging to group k,
E_{ij}, emission of pollutant i from the single activity j.

Assignment of the scores directly on point source emissions

In the cases in which emissions data are collected at the sources and are obtained through analysis on the smokes outgoing from the stacks, the score of every of the four criterions immediately is assigned to the emissions, therefore without calculating it as the multiplication of the score of the indicator of activity by the score of the emission factor.

Specifically, in the case of continuous measurement of emissions, the assigned score is 10 for the criterion measurement, 10 for the specificity of the source, 10 for the spatial congruity and 10 for the temporal congruity (unless analyses make reference to one different year from that considered; in this case the assigned score will be smaller, according with the temporal congruity discussion in the next chapter). If emissions are calculated through periodical measurements, assigned scores are 8 for the criterion measurement, 10 for the specificity of the source, 10 for the spatial congruity and 10 for the temporal congruity (only if the year of reference of the analyses is that in consideration).

Assignment of the scores for activity data

The methodology DARS has been personalized to the goals of a greater correspondence to the territorial reality that the regional inventory wants to represent. The following tables show the criterions of assignment of the scores for activity data.

Table 2 - Measurement/Method

Activity	Score
Production or consumption data declared by the facility (area or point sources)	10
Surface data drawn by Land Cover Maps (for example: "11060100 Lakes" and "11060500 Rivers")	10
Activity data related to linear/nodal sources estimated through systematic counting (traffic count, number of aircraft, number of ships) and detailed for inventory's classes	10
Activity data related to linear/nodal sources estimated through systematic counting (traffic count, number of aircraft, number of ships) for classes wider than those of the inventory	8
Activity data evaluated by surrogate data of produced quantity or treated quantity	8
Activity data statistically evaluated	8
Activity data related to linear/nodal sources estimated through traffic models for classes wider than those of the inventory	6
Activity data derived from a different measured surrogate associated with original activity surrogate	6
Activity data evaluated through models	6
Activity data related to linear/nodal sources estimated using “occasional” counting data	4
Activity rate derived from engineering or physical principles	3
Activity estimate based on expert judgment	1

Table 3 - Source Specificity

Activity	Score
Activity data that exactly represent the emission process	10
Activity data related to specific linear/nodal source	10
Activity very closely correlated to the emission activity	9
Activity data for a similar process that is highly correlated to the category or process (ex. number of vehicles registered in the year instead of vehicles dewaxing)	7
Activity data are somewhat correlated to the category or process	5
Activity data represent a surrogate source category with limited information	3
Activity data for a surrogate source category and applied through expert judgment	1

Table 4 - Temporal Congruity

Activity	Score
Activity data representative of the year of the inventory	10
Activity data representative of the same year, but based on an average over several repeated periods	9
Activity data representative of a different year with a low temporal variability (for example vegetation coverage)	8
Activity data representative of a different year with a moderate to low temporal variability	7
Activity data representative of a different year with an high to moderate temporal variability	5
Activity data representative of a different year with an high temporal variability	3
Activity data representative of a different year with difficulty to assess temporal variability	1

For spatial congruity the European Union Nomenclature of Units for Territorial Statistics (NUTS) / Local Administrative Units (LAUs) is used. NUTS classification was created by the European Office for Statistics (Eurostat) as a single hierarchical classification of spatial units used for statistical production across the European Union. At the top of the hierarchy are the individual member states of the EU: below that are levels 1 to 3, then LAU levels 1 and 2. Note that LAUs were only introduced in July 2003; before this there had been 5 different NUTS levels. Area sources are actually evaluated at the lowest level: LAU2.

Table 5 - Spatial Congruity

Activity	Score
Activity data available to municipal (LAU 2) level	10
Activity data related to point or linear/nodal sources (traffic count, number of aircraft, number of ships)	10
Activity data available at provincial (NUTS 3) level with availability of proxy at municipal (LAU 2) level: proxy strongly correlated with activity	9
Activity data available at regional level (NUTS 2) with availability of proxy at provincial (NUTS 3) and municipal (LAU 2) level: proxy strongly correlated with activity	8
Activity data available at provincial (NUTS 3) level with availability of proxy at municipal (LAU 2) level: proxy weakly correlated with activity	7
Activity data available at regional level (NUTS 2) with availability of proxy at only municipal (LAU 2) level: proxy strongly correlated with activity	7
Activity data available at regional level (NUTS 2) with availability of proxy at provincial (NUTS 3) and municipal (LAU 2) level: proxy weakly correlated with activity	6
Activity data available at regional level (NUTS 2) with availability of proxy at only municipal (LAU 2) level: proxy weakly correlated with activity	5
Regional activity data unknown and evaluated from national total with availability of proxy to provincial and municipal (LAU 2) level	4
Regional activity data unknown and evaluated from national total with availability of proxy to municipal (LAU 2) level only	3

Assignment of the scores for emissions factors

The scores for the criterion of measurement are assigned in base to the evaluations reported by the source of origin of the same factor. Usually to the emission factor it is associated a code (A to E) that gives an idea of the precision of the datum, as used for emissions factors in US EPA AP-42[6].

In European Environmental Agency Atmospheric Emission Inventory Guidebook[7] a methodology is provided for representing the general quality of the emission factors. The respect of the quality of the datum is assigned in accord with the definitions reported in Table 6. In the table is associated to every rate an interval of percentage values of uncertainty of the emission factor.

Table 6 – Uncertainty rating for emission factors as defined by EEA Emission inventory

Rating	Definition	typical error range
A	An estimate based on a large number of measurements made at a large number of facilities that fully represent the sector	10 to 30 %
B	An estimate based on a large number of measurements made at a large number of facilities that represent a large part of the sector	20 to 60 %
C	An estimate based on a number of measurements made at a small number of representative facilities, or an engineering judgment based on a number of relevant facts	50 to 150 %
D	An estimate based on single measurements, or an engineering calculation derived from a number of relevant	100 to 300 %
E	An estimate based on an engineering calculation derived from assumptions only	order of emagnitude

The methodology DARS provides the attribution of numerical scores for each of the codes assigned to the emission factors of the principal pollutants in US EPA AP-42[6]. In Table 7 the appropriate conversion table is reported. The same score in Table 7 are assigned to the category in EEA of Table 6.

Table 7 –AP-42 uncertainty codes and corresponding DARS scores

	Nitrogen dioxides	Sulfur dioxides	Carbon monoxides	Volatile organic compounds	Suspended particles (less than 10 μ diam.)
A	6	6	6	5	5
B	6	6	6	5	5
C	5	5	5	4	4
D	5	5	5	4	4
E	4	4	4	3	3

In the following tables are reported the procedure for assignment of the scores referred to the emission factors relatively to the specificity of the source (Table 8), spatial congruity (Table 9) and temporal congruity (Table 10).

Table 8 - Source Specificity

Emission factor	Score
Factor developed specifically for the intended source category or source	10
Factor developed for a subset or superset of the intended source category. Low variability (<10%)	9
Factor developed for a similar category with low variability (<10%) and correlate to category	8
Factor developed for a similar, subset or superset of the intended source category with variability from low to moderate (10%-100%)	7
As of precedent but with variability expected from moderate to high (100%-1000%)	6
As of precedent but with high expected variability (>1000%)	5
Factor developed for a surrogate category with limited information	3
Factor developed for a surrogate category and applied through experts judgment	1

Table 9 - Spatial congruity

Emission factor	Score
Factor developed for and specific to the given spatial scale	10
Factor developed for a region larger or smaller than the one applied to, or for a different region of similar size. Variability expected low (<10%)	8
As of precedent but with variability expected moderate (10%-100%)	7
As of precedent but with variability expected moderate to high (100%-1000%)	5
As of precedent but with variability expected high (>1000%)	3
Factor developed for an unknown spatial scale or spatial variability is unknown	1

Table 10 - Temporal congruity

Emission factor	Score
Factor developed for and applicable to the same temporal scale (for example the same year)	10
Factor derived from periodic measurements in the same temporal domain	9
Factor derived for a longer/shorter period, or for a different year. Variability expected low (<10%)	8
As of precedent but with variability expected low to moderate (10%-100%)	7
As of precedent but with variability expected moderate to high (100%-1000%)	5
As of precedent but with variability expected high (>1000%)	3
Factor of which it is difficult to establish the temporal variability for lack of data	1

EMISSION INVENTORY SOFTWARE

The APEX emission inventory software is integrated in the computer models system AIR SUITE developed by Techne Consulting. In the following a brief description of the system is reported as an introduction to uncertainty APEX module. The air suite system schema is reported in Figure 1.

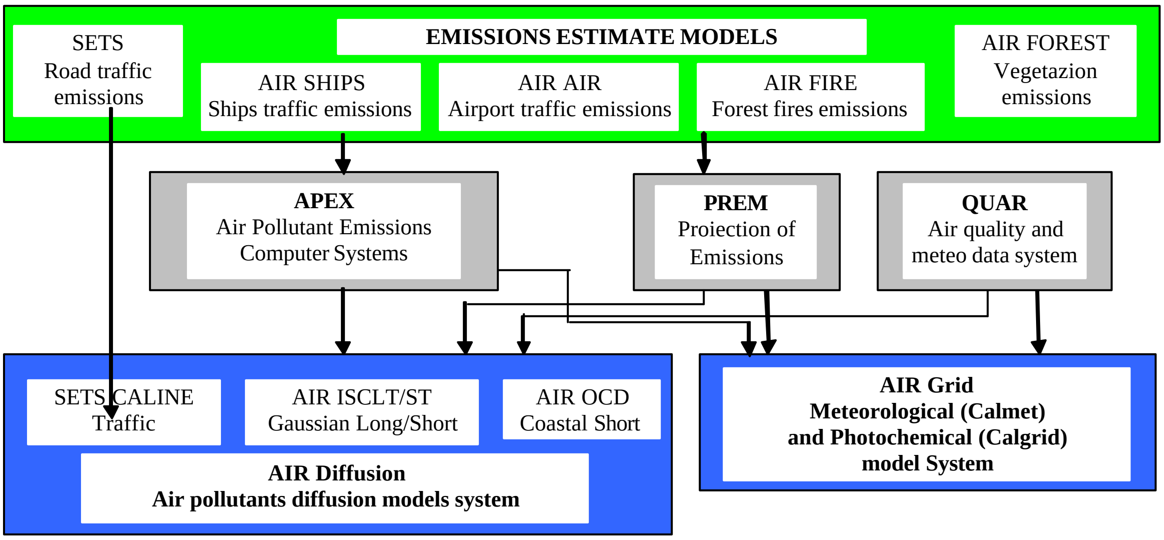

Figure 1: Structure of information system for air quality management planning

APEX

APEX, an air pollutant emissions computer system originally developed in the Windows environment with object-oriented ORACLE CARD tool[9,10,11] and with Visual Basic language, and available with an ORACLE or SQL Server database[12,13,]; the system contains an emission factors data base and tools and data to estimate grid and municipal emissions from more aggregated data[14], the system uses Arc View or MapInfo for thematic map. Recently integrated emission inventory computer system was realized that allow the realization of emission inventory in different media (air, water, wastes, etc.)[15]. In Figure 2 and Figure 3 the Area, Line and point source view are reported with the evidence of uncertainty entities.

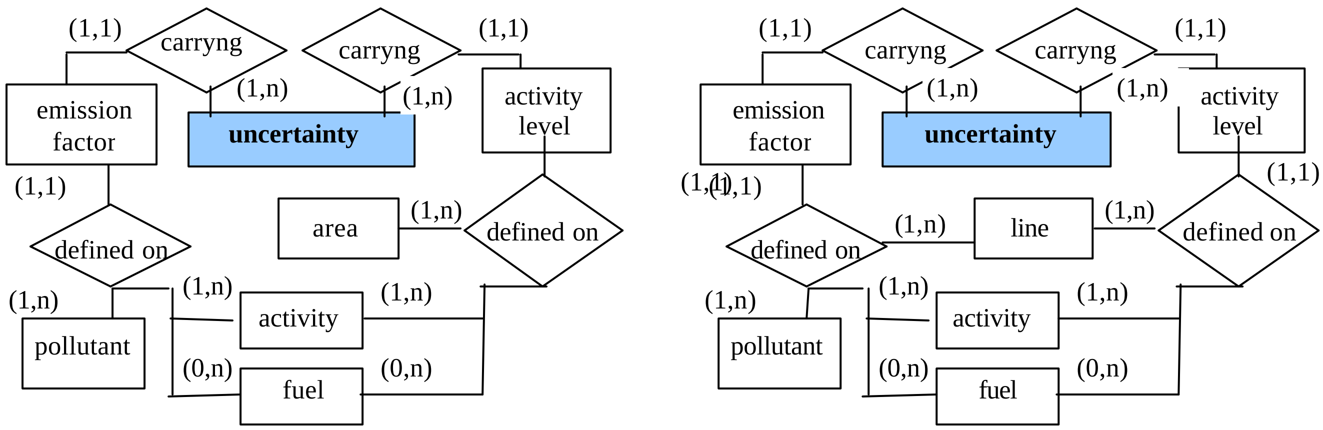

Figure 2 - APEX "Area and Line sources data" views

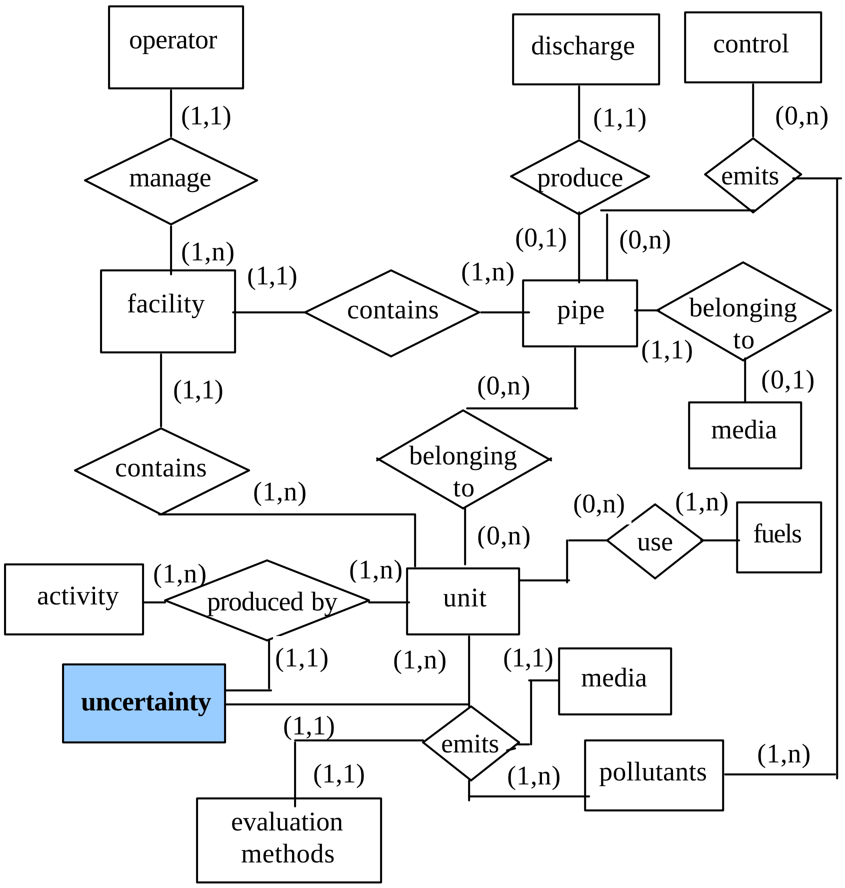

Figure 3 - APEX "Point sources data" views

CASE STUDY

The procedure described in the paper has been applied to some case studies of regional and sub regional emission inventories in Italy. In Table 11 an example of the results of application, Toscana regon, is reported. Uncertainty is evaluated as described in the paper for single activity and global uncertainty is computed by (1).

Table 11 – Average uncertainty score for regional case study application of methodology

Macrosectors	CO	COV	NO_x	PM_{10}	SO_X
Combustion in energy and transformation industries	8,18	7,33	9,80	8,69	9,90
Non-industrial combustion plants	7,18	6,94	6,58	7,17	7,06
Combustion in manufacturing industry	8,19	7,36	8,50	7,43	8,87
Production processes	7,75	6,76	8,35	7,09	8,95
Extraction and distribution of fossil fuels and geothermal energy		6,74			
Solvent and other product use		6,66		8,37	
Road transport	7,22	7,04	7,29	7,09	7,27
Other mobile sources and machinery	7,19	6,98	7,32	7,19	7,20
Waste treatment and disposal	7,57	7,75	8,80	7,28	8,54
Agriculture	6,45	6,65	6,45	6,25	
Other sources and sinks	6,60	6,00	6,60	6,45	
TOTAL	**7,26**	**6,78**	**7,88**	**7,28**	**9,65**

CONCLUSIONS

In the paper are discussed the methodology and the computer model for introduce uncertainty in regional air pollutant emissions inventory in Italy. The general methodology proposed by EPA EIIP and referred as DARS has been personalized to the goals of a greater correspondence to the territorial reality that the regional inventory wants to represent. The uncertainty is introduced in the general design of the Air Pollutants Emission Computer System (APEX) and in the user interface.

A first broad application of the methodology and software for a complex regional inventory has been recently concluded. First results for a case study has been reported in the paper.

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