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# a computer-oriented emissions inventory procedure for urban and industrial sources

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A knowledge of the rate of emission of atmospheric pollutants is essential for the enforcement of air quality control policies. A computer-oriented emission inventory procedure has been developed and applied to Venice, Italy. By using optically readable forms this procedure avoids many of the errors inherent in the transcription and punching steps typical of approaches applied so far. Moreover, this procedure allows an easy updating of the inventory. Emission patterns of $SO_2$ in the area of Venice showed that the total urban emissions were about 6% of those emitted by industrial sources.

A knowledge of the rate of emission of atmospheric pollutants is essential to both local authorities and to scientists as a basic evaluator of expected pollution levels and distributions, and as input data for mathematical air quality models. The present inventory is only concerned with stationary sources of pollutants which have been grouped in two different categories. The first one includes all the emissions due to industrial activities, while the second one, termed from now on 'urban emissions' includes all the emissions caused by activities different from the previous one, i.e. space heating, commercial activities, etc. The emissions due to transportation have been neglected until now in investigations carried out in the area of Venice as these studies have only been concerned with $SO_2$ pollution. In Venice the pollution problem is worsened by damages produced by pollutants to the artistic patrimony of the city, already threatened by the unique environmental conditions of recurring floods (the well-known phenomenon of 'acqua alta'), salinity, and high humidity.



The Venice area (Figure 1) is in northeastern Italy at the northern edge of the Adriatic Sea. It includes the urban centers of Mestre, Marghera, and Venice, as well as a large industrial area. The urban centers of Mestre and Marghera are on the mainland and cover a surface of about 10 km$^2$. The main activities of the industrial area, which covers an area of 20 km$^2$, are oil refining, petrochemical production, metallurgy, and electrical energy production. The historic center of Venice is located 6 km from the mainland in the middle of a lagoon, which is separated from the Adriatic Sea by narrow strips of land.

Venice covers an area of 6 km$^2$ and stands on a cluster of small islands separated from each other by a network of narrow canals and interconnected by several bridges. Due to its peculiar location and history, its structures have not undergone the significant modifications and growth typical of other cities.

A desire to save this unique city and the need to plan industrial activity have led public and private groups to analyze its air pollution problem. As part of this effort, analyses have been carried out on the observed $SO_2$ distributions[1] and on the climatology of the area.[2] In addition, Gaussian[3] and stochastic[4] models have been utilized to investigate the interactions between the dynamics of the local boundary layer and pollutant concentration.

These models have utilized a source emission inventory compiled by the regional government in 1972. In carrying out this inventory the industries were not required to fill some standard forms, but only to supply the pollutant average emission rates, the temperature of the exhaust gases, and the location and height of the emissions.

In the present study, a computer-oriented emission inventory procedure (CEIP) has been developed in order to obtain an inventory of stationary area and point source emissions and an application has been made to the Venetian area. Emissions from non-stationary sources can be included in the procedure at a later date.

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## Emissions Inventory Procedure

### Industrial Emissions

The organization of an industrial emission inventory usually causes problems to both the group carrying out the inventory and the industries providing the information. The latter must accomplish the task of completing special forms which can sometimes be obscure and rather complicated, while the former must design those forms to be as complete and as rational as possible. The group carrying out the inventory must also exact the information that they originally intended to gather from the compiled forms.

It is apparent that the work of interpretation and, as far as possible, of correction of information collected can best be carried out using a digital computer. It is therefore advisable that the data be collected on a form which is directly accessible by the computer. Some previous inventories of industrial emissions have been carried out using forms which were organized so that data could be directly transferred to punched cards.[5,6] In these forms the information required concerned the normal and peak overall emission rates, the location and height of stacks, the characteristics of abatement equipment, and the normal plant operating schedule. In general these forms required the type of plant or the type of process as basic information from which composition of exhaust gases was determined by using suitable tables given for each industrial activity. In the new procedure a further step towards automation has been made by the use of optical forms, i.e., special forms which can be 'read' by an optical reader, whose output is a magnetic tape which can be directly processed by a computer.

The flow-chart in Figure 2 shows the various steps that each of the three different types of procedures requires. Procedure (b), which is the most commonly used avoids the transcription phase; yet errors can still be made both during the form completion and the card punching. The former consist of wrong answers given to the requests appearing in the form and cannot generally be identified automatically. The latter, on the contrary are due to an incorrect punching of the values reported in the forms, such as punching values in the wrong card field, punching a wrong digit or even neglecting to punch some digits or a whole value. Most of these errors cannot be recovered. It is apparent that in the proposed procedure they are completely avoided since the forms are transferred directly from the person who completes them to the computer. This also results in time saving. Obviously this procedure does not avoid the errors occurring during the form completion. However the forms completed not according to the rules inherent in the structure of the optical reader are immediately found, as they are discarded by the optical reader. These forms must be sent back to the industries for recompilation.

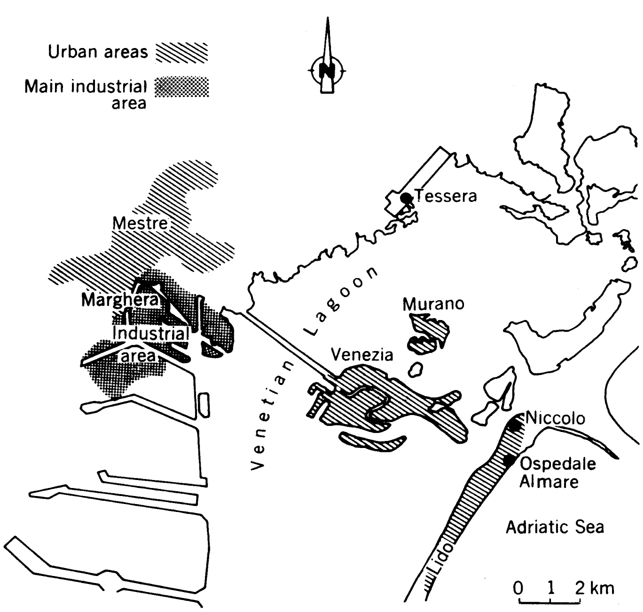


**Figure 1.** Venetian region including urban areas (Venice, Mestre, and Marghera) and main industrial area.

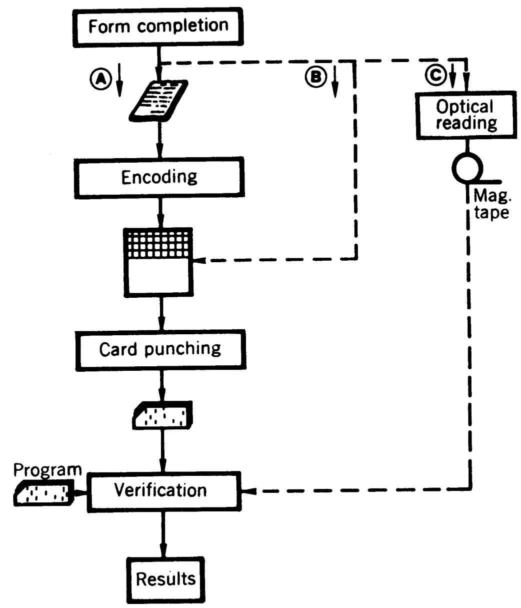


**Figure 2.** Schematic representation of three different emission inventory procedures as follows: a) no use of encoding forms or optical reader; b) use of encoding forms, but no use of optical reader; and c) use of both encoding forms and optical reader.

The basic philosophy of the CEIP methodology is that an inventory must be made, not of the total annual emission from a particular stack, but of the individual releases associated with each of the various industrial processes causing an emission from the particular stack. In Figure 3, for instance, the emission of stack No. 8 consists of a single release, which can be either continuous or discontinuous, produced by two different processes A and B, yielding two simultaneous emission stages $A_1$ and $B_1$. On the contrary, the emission of stack No. 15 consists of three different releases which are necessarily not simultaneous. Precisely, release No. 1 is produced by three processes A, B, and C each yielding a single emission stage $A_1$, $B_1$, $C_1$; release No. 2 is due to emission stage $D_1$ produced by process D, and, finally, release No. 3 is due to emission stage $D_2$ produced by process D and to emission stage $E_1$ (simultaneous to D) produced by process E.

In practice for every process the different emission stages must be identified in terms of flow rate, chemical composition, and duration period. By adding the simultaneous emission stages discharged through the same stack the chemical composition and the flow rate of each release are obtained.

The CEIP methodology requires that two different forms: A and B, be completed for each release. For instance, for case 1 in Figure 3 only one pair of the above forms must be used, while for case 2 three pairs of forms must be completed. Form B is the one read by an optical reader, while the information contained in form A may be transferred to punched cards, if needed.

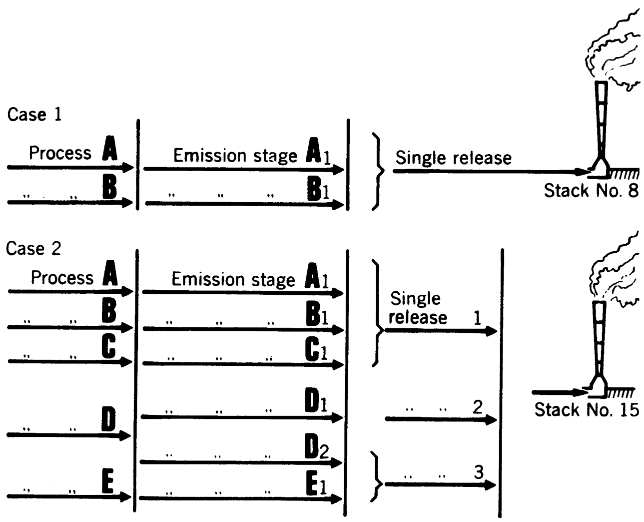


**Figure 3.** Examples of possible emission patterns from a single stack. In Case 1, one pair of forms is required, while for Case 2, three pairs of forms must be completed.

The information contained in form A includes name and address of the firm, a short description of the processes yielding the release, and of the abatement equipment (if any). In addition, if the process is a combustion, the characteristics of the fuel used are reported.

Information contained in form B concerns the location of the stack, its diameter, its height above both ground and sea level, the temperature of exhaust gases, the overall emission rate of the release, its chemical composition, its duration and frequency of occurrence (times per day and days per year). From the last information the procedure results as intermediate between simply dividing the annual emission from a single point source by the total number of hours of operation (known or estimated) and compiling an hour by hour emission inventory for each point source.

The CEIP methodology was applied to the Venetian area in 1974. The percentage of forms rejected by the machine because of improper compilation, as above defined, was only about 2%. This does not necessarily mean that all of the answers in the remaining forms were correctly entered. Analysis of the forms showed that most omissions were due to a lack of knowledge, rather than to a difficulty in understanding the procedure for filling in the forms.

The processing procedure applied to the collected information is shown in Figure 4 and includes the following steps: a) forms are read by the optical reader and their contents are transferred to a magnetic tape; b) data on the tape are checked by a program which detects errors and omissions, and creates a tape containing correct data and one containing incorrect data; and c) the errors are checked by contacting those who completed the form. The errors detected in step b) are essentially:

1. Stack coordinates otuside of the area considered.
2. Inconsistency of the information concerning the frequency of the emission.
3. Inadmissible concentrations of pollutants in the exhaust gases.

However, the occurrence of the above errors was practically negligible.

**Urban Emission Inventory**

The source of data for estimating the spatial distribution of urban emissions was: 1) data gathered in the national census of 1972 in which it was requested to specify the type of fuel used in the different urban activities, and 2) the total usage of natural gas in the Venetian area, obtained from the local gas company.

The urban districts of the Venetian area were divided into 272 sections, for each of which the following information was known: number of inhabitants and percentages of persons using each of the following energy sources—gas, oil, coal, wood, and electricity. A 'per capita thermal need' was determined, and was assumed to be independent of the fuel used. This parameter was estimated from the overall yearly consumption of natural gas which was known.

With the above data, the following equation was used to estimate the total annual emission of $SO_2$ in each of the 272 sections:

$$E_i = \sum_j P_{ij} \frac{Q}{q_j} S_j$$

where:

$E_i$ is the annual $SO_2$ emission in the $i$-th section in kg/year,
$P_{ij}$ is the number of persons in the $i$-th section using the $j$-th fuel,
$Q$ is the 'per capita thermal need' in kcal/(person.year),
$q_j$ is the thermal content of the $j$-th fuel in kcal/kg, and
$S_j$ is the $SO_2$ content of the $j$-th fuel.

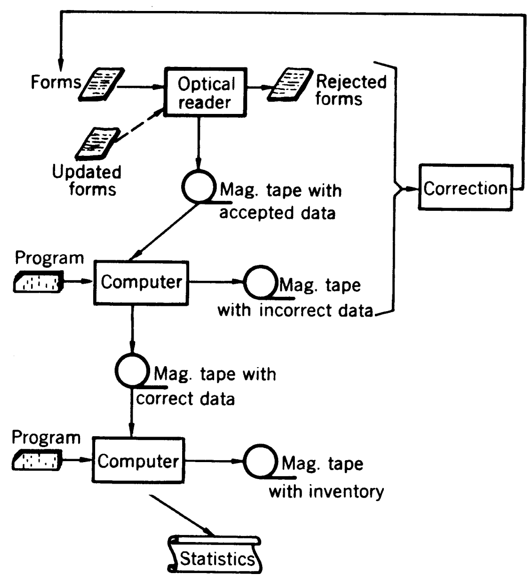


**Figure 4.** Schematic representation of the processing of data on forms to produce an emission inventory.

The computed annual usage of the individual fuels are in good agreement with rough estimates supplied by wholesalers in the area. In the climatological model reported in an earlier paper,[3] the urban area source emissions were introduced as 'equivalent' point sources located in the center of each of the sections, with an assumed effective stack height of 30 m for the historical center of Venice (where the buildings are generally old and low) and of 45 m for the urban areas in the mainland (which have developed in the last three decades and have taller buildings).

The data supplied by the local gas company showed that the percentage of natural gas burned for space heating is about

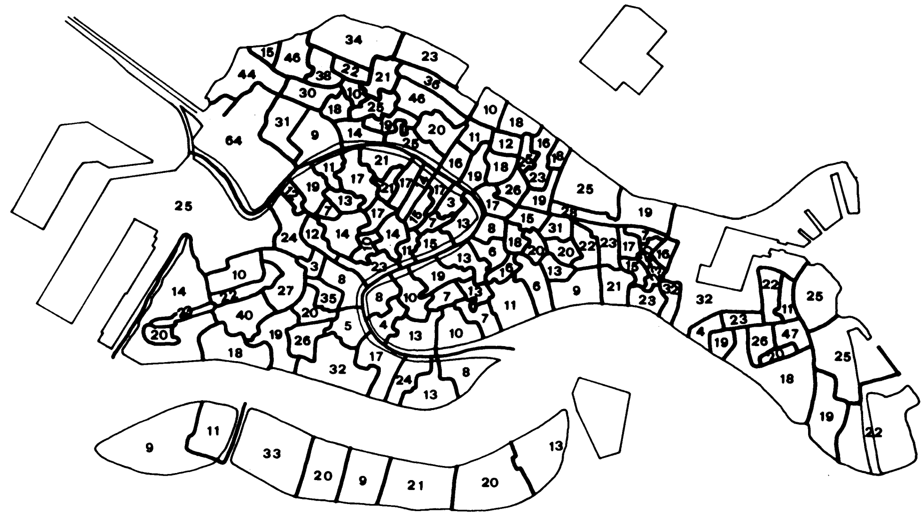

**Figure 5.** Annual area source emissions of $SO_2$ from Venice in 1972 (in tons/year)

90%, while the remainder is used in the other urban activities. Assuming that this ratio is also valid for the other fuels the temporal distribution of urban emissions was computed by adding two different contributions:

a. A constant one due to all the urban activities different from space heating;
b. A seasonally varying one due to space heating.

The seasonal variation of contribution (b) was computed by using the values of degree days, which are defined by:

$$dd = T_b - \frac{1}{24}\sum_{n=1}^{24} T_{h,n} \quad \text{for } \overline{T} \le T_b$$

$$dd = 0 \quad \text{for } \overline{T} > T_b$$

where:

$T_b$ is the temperature at which heating starts, found to be 15.5°C in Venice,
$T_{h,n}$ is the average hourly temperature at the $n$-th hour of the day, and
$\overline{T}$ is the average daily temperature.

The $SO_2$ emission rate $e_{i,k}$ (in kg/sec) for the $i$-th section in the $k$-th period of time is then:

$$e_{i,k} = \frac{E_i \cdot \mathrm{dd}_k}{N_s \cdot \mathrm{dd_a}}$$

where:

$dd_k$ is the number of degree days in the $k$-th time period,
$dd_a$ is the total number of degree days in one year, and
$N_s$ is the total number of seconds in the $k$-th time period.

The above equation is valid only for periods greater than one day, while for shorter time periods information concerning the diurnal cycle of emission must be obtained.[7]

## Results

Analysis of the gathered data shows that the total annual point source emission of $SO_2$ is approximately 160,000 tons.

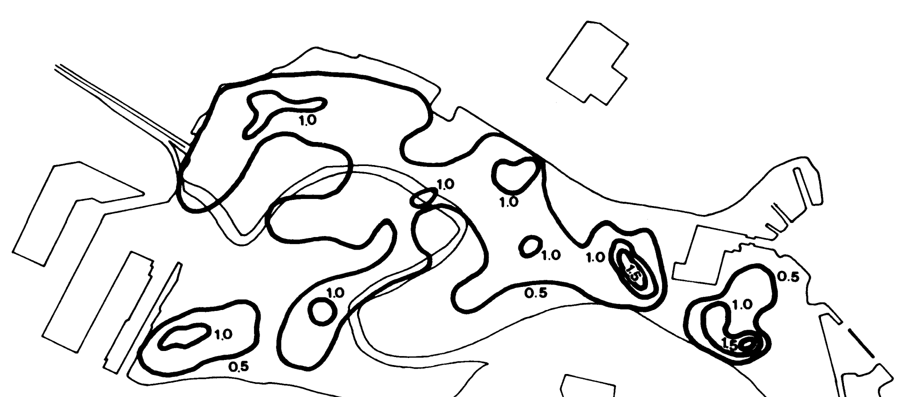


**Figure 6.** Isopleths analysis of $SO_2$ emission intensity in Venice in 1972 (in kg/m$^2$.year).

Of this amount about half is released into the atmosphere for production of electricity. The above results are in agreement with the estimates given by the emission inventory compiled in 1972, which is a further confirmation of the validity of the proposed methodology.

Urban activity gives to $SO_2$ emission a contribution of 10,000 tons/year. In particular, the distribution of $SO_2$ area source emissions from the city of Venice is shown in Figure 5. In addition, in order to obtain a better insight into the spatial variability of $SO_2$ emissions in Venice, the distribution of emission intensity (defined as emission per unit area per unit time) was computed (Figure 6). Results show a fairly uniform distribution of emission intensity, with several small regions showing higher values. This type of pattern is to be expected due to the uniform building density in Venice. Incidentally, the total annual area source emission of $SO_2$ in Venice in 1977 is probably less than that of 1972 due to the large number of persons changing their heating system to one that uses natural gas, which is prescribed by a national law as the only fuel to be used in Venice.

## Conclusions

The computer-oriented emissions inventory procedure (CEIP) described in the present paper has been shown, by its application to Venice, Italy, to be a workable approach for compiling emission inventories for air pollution applications. Its main advantages lie in that it is almost totally automatic, and in its basic philosophy, which states that summaries should be made, not of the total annual emission from a particular stack, but of the individual releases associated with each of the various industrial processes resulting in an emission from that particular stack.

The proposed methodology avoids many of the errors inherent in the encoding and punching steps typical of other approaches. The use of 'optically readable' forms is both dynamic and flexible in that the inventory can easily be partially or totally updated, and that forms can be modified for use in different applications.

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