Status Report

THE FEASIBILITY OF EMISSION INVENTORY TOOLS FOR URBAN AREAS IN LESS DEVELOPED COUNTRIES

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Executive Summary

The lack of knowledge of sources and amounts of air pollutant emissions is a major obstacle for the introduction of efficient control actions. Computerized software packages could serve as tools for

- establishing inventories of air pollutant emissions in data-poor environments, and
- for the transfer of know-how on the identification and evaluation of emission sources.

The paper analyzes the feasibility of an computer-based tool to facilitate the estimate of emissions to the atmosphere, with particular reference to situations with incomplete information. The feasibility study shows that, in principle, the development of a software package to support local staff in estimating emissions is feasible. However, the envisaged system should take account of the following basic aspects, which seem of crucial importance for successful dissemination and use of the tool in developing countries:

- It is of utmost importance that the software be easy to use also by inexperienced persons. Provision of all necessary calculation routines, a user-friendly interface and the use of standard MS-DOS based computer hardware will be important elements for a successful dissemination of the tool.

- It is recommended that the source categories to be considered in the inventory should be based on existing emission inventory standards (such as the European CORINAIR system or the US-EPA accounting). These lists must be supplemented by activities important in developing countries (e.g open burning of wastes, etc.).

- Default emission factors should be taken from existing data bases (e.g. LEAP/EDB, CORINAIR, etc.), but their applicability for situations in developing countries be reviewed in an expert meeting.

- The inventory calculation routines should be supplemented by an expert system for providing alternative surrogate data and for interactive training.

- Routine uncertainty analysis should be incorporated. Such uncertainty analysis does not put an additional burden on the individual user of the emission inventory tool, but could greatly improve the accuracy of estimates by focusing attention on the most influential areas.

- There exists a trade-off between the efforts put into the development and refinement of the software package and the time the individual user will need to get acquainted with the system, and to successfully establish an emission estimate. It is strongly suggested to invest more into the development phase and obtain a package that can be easily applied to many cities.

- A rough estimate of the manpower efforts required to develop a comprehensive package which takes into account the aspects discussed in this paper is 34 person months of experts' work.

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1. Introduction

1.1 Background

In many countries the current levels of air pollution are recognized as a potential hazard for human health, natural ecosystems and man-made materials. In particular, high ambient concentrations of pollutants coincide with high population densities in urban areas, leading to a high risk of damaging the health of the population. Approximately 1.2 billion city dwellers world-wide are exposed to excessive levels of sulfur dioxide, and nearly half of the cities monitored within UNEP's GEMS/AIR network have levels of nitrogen dioxide that exceed official World Health Organization (WHO) guidelines. Carbon monoxide levels in more than half the cities exceed the WHO standards (UNEP, 1991).

Whereas in developed countries counteractions to reduce air pollution have already been initiated and, as a consequence, levels of urban air pollution are falling, air pollution in cities in developing countries is still increasing. For example, the World Watch Institute, Washington D.C., has estimated that a vendor sitting in his shop on a major thoroughfare of Bangkok, Bombay or Jakarta will by the day's end involuntarily have breathed in toxic chemicals and gases equivalent to more than nine cigarettes.

Efficient strategies to reduce air pollution require knowledge about sources and magnitudes of emission releases. Reliable emission estimates are necessary for identifying the major sources contributing to the problem in a specific region and are therefore an essential basis for cost-effective emission control. Furthermore, data bases on emissions are a major input of air quality models, which can, together with techno-economic data on the emission sources and control options, also provide relevant information for optimal emission abatement strategies.

In many cases, in particular in less developed countries, information on emission sources is scarce. A generally applicable tool, easy to use, to assess sources and magnitudes of emissions to the atmosphere would provide essential information to focus resources for the improvement of air urban quality most efficiently. Furthermore, it would serve as an important teaching and training tool for the transfer of knowledge on emission accounting to situations, where such knowledge is urgently needed.

1.2 Emission inventories in developing countries

Over the last few years various methodologies for establishing emission inventories have been developed and widely applied to national, regional and urban emission accounts in industrialized countries. In contrast to this, applications in developing countries have been limited to a few cases, although the current levels of air pollution observed, at least in urban areas, would definitely justify major efforts to identify and quantify major sources of emissions. A general dissemination of emission inventory activities in developing countries is currently hampered mainly by two circumstances:

- The data availability appears to be insufficient to implement simple approaches for emission estimates.
- The lack of expert knowledge, in particular in emission inventory techniques, prevents local professionals from carrying out the necessary activities.

Recent scientific progress now enables both the development of tools for deriving rough emission estimates even in the absence of full information, and the incorporation of advanced techniques of expert systems to simplify the compilation of emission inventories. Such systems, properly designed, will also serve as training tools and as efficient means for transfer of know-how to developing countries.

1.3 Objective of this paper

This paper explores the requirements for a computer aided tool to facilitate estimating the air pollutant emissions of urban areas in developing countries and analyzes the feasibility of developing a software package. Emphasis is given to:

- identifying and ranking the most important variables and parameters determining emission levels which should be covered by the emission inventories,

- the possibilities for deriving estimates in a data-poor environment,

- the easy applicability and user-friendliness of the system,

- the potential role of the tool for training purposes, and

- the possibility for continuous updating of the system by introducing new research results at a later date.

The remainder of this paper is organized as follows: Section 2 reviews the major purposes of emission inventories and derives from this the most important features of a useful inventory tool. Section 3 discusses some general considerations which will be decisive for the applicability of an emission inventory tool, in particular the human interface of a computerized inventory tool, the basic approaches of emission accounting, the achievable accuracy and the remaining uncertainties of the results. Section 4 assesses the major components of emission inventories (pollutants, emission generating activities) and explores the level of detail that is feasible to maintain, even with limited data availability, as well as guaranteeing meaningful and relevant results. Aspects of the practical implementation of a software package, such as the use of expert systems techniques, the hard- and software configurations and training demand, are discussed in Section 5. Finally, the manpower requirements for developing the emission inventory tool are estimated in Section 6.

This feasibility study addresses the specific situation of cities in less developed countries and explores the possibility of compiling emission estimates as a priority with the aim to support strategic decisions to reduce air pollution.

2. The purpose of emission inventory tools

Emission inventories provide information on emission sources within a specific region. Usually they contain data for individual large point sources (e.g. power stations, large industries, etc.) and distributed area sources (emissions from households, traffic, etc.). Information provided for these categories relate to the individual emission generating activites, their location and the magnitudes of emissions for several pollutants over a defined time. In some cases also techno-economic properties of the sources, such as size and age of plants, fuel consumption, existing emission control devices, etc. are stored in the data base.

Before deciding on the detailed design of an inventory system it seems important to explicitly define the goals of performing emission inventories and their envisaged final use.

Knowledge of the various sources of air pollutants and the determination of their contribution to the overall pollution is a first step towards an effective pollution control. Thus, the most important use of emission inventories is to provide a sound basis for **strategic decisions** on emission reductions by identifying the sources and magnitudes of individual emission releases. The relevant aspects of a prospective inventory for this purpose are:

- the completeness of the inventory, in particular in terms of the major emission sources,
- the knowledge of major techno-economic features of emission sources, such as plant size, technology, age structure, activity level, capacity utilization, quality of fuels, etc.

Emission data is also an essential input for the development, validation and operation of **atmospheric dispersion models** on the local, regional and global scale. Information relevant for this purpose is:

- knowledge of the physical features of emission sources, e.g. stack height, gas temperature, etc.,
- the chemical properties of pollutants, such as profiles of VOC components (see Simpson, 1991) etc., and
- the temporal pattern of emission releases, e.g. seasonal, diurnal variations, etc..

Dispersion models are required to accurately estimate the contribution of individual emission sources to ambient pollution concentrations in a region. This might be of importance for strategic decisions for measures to improve e.g. air quality in a city.

Furthermore, emission inventories are required to establish cause-effect relationships between ambient concentrations of pollutants and e.g. **human health**. Such relationships will need emission inventories to link ambient pollution concentrations, as monitored in many cities, with the sources of pollution and, thereby, provide guidance for measures to protect public health in urban areas.

With lower priority, emission inventories are also required as input to **environmental statistics**, which are considered as relevant for evaluating the performance of environmental policies. The most important properties of emission inventories for matching such requirements are:

- that the aggregation of individual emission sources into groups, e.g. of economic activities, be consistent with general national statistics, and
- that the spatial aggregation of the sources be in line with the established territorial units of other, already established statistics.

2.1 Creating the basis for optimized (cost-effective) pollution control

The decision as to which purpose an inventory should serve strongly influences the design of the envisaged inventory tool. Since, as indicated above, **strategic decisions are of highest importance**, the output of emission inventories should provide all necessary information for the design of cost-effective emission reduction strategies: Reliable information on the sources of air pollution is a basic requirement for more complex decisions on cost-effective emission reduction strategies. For this purpose, accurate information on large emitters (including techno-economic parameters, such as technology type, size of the facility, age structure, etc.) is essential in an emission inventory. Provisions should be made for any requirements of possible air quality modelling studies which have proved most useful in the quantification of emission reductions in order to achieve 'safe' levels of ambient air concentration. Compared to these primary goals, the need for data to match national or international statistics seems of less importance. However, it should be noted that a likely result of a careful design to provide the strategic information will also yield sufficient data to be used in environmental statistics.

2.2 (Human) capacity building

As mentioned in the introductory section, reliable information on emissions from some developing countries is scarce. Many factors can be identified as possible reasons for this lack of knowledge, e.g.:

- the limited financial resources available to identify and quantify emissions, and
- limited access to emerging sophisticated methodologies on establishing such inventories.

Emission inventory tools can be used to overcome these problems in several ways:

- Knowledge about the largest emission sources in a region will be an eminent element in the process of raising public awareness for air quality problems in a region.
- Highly developed knowledge on emission accounting will be transferred to local experts, who will also acquire a sound technical basis for evaluating air quality problems.

Therefore, the second, extremely important aspect of the envisaged new system will be its potential role in creating local expertise in less developed countries. Whereas other existing software packages, such as the CORINAIR software, allow well trained experts to estimate emissions, they fall short of communicating the basic principles of emission calculations to less experienced users. It is strongly recommended that any development of an emission inventory system explicitly takes proper account of this educational function, and applies the latest techniques to enable the transfer of knowledge to local experts. Consequently, it will be necessary to allocate sufficient resources also for the development of these educational components.

3. General considerations for an emission inventory tool

This section discusses some general aspects that are important to derive basic requirements for a tool to develop emission inventories, focusing on urban areas in developing countries.

3.1 The human interface

To enable a wide international dissemination of inventory activities it seems crucial to visualize the probable local situation:

- that the prospective user has only limited experience in computer use,
- that hardware resources available for this task are restricted, and
- the users have limited experience in establishing emission inventories.

Thus, it is essential that the software package takes explicit account of the following aspects:

- easy implementation of the software on widely available, affordable standard computer hardware (e.g. personal computers),
- a user-friendly guidance through the system to ensure proper and complete performance of all subareas of the inventory,
- provision of the most up-to-date methods to estimate emissions, with implemented algorithms for estimates and a proper explanation of the methodologies applied,
- (in absence of full information) the possibility to apply techniques to determine emission levels based on surrogate data, and
- a clear and transparent documentation of the individual steps taken to derive the estimates, so that the entire process of the inventory creation, including the assumptions made, can be reproduced and, if necessary, improved at a later date.

These aspects will be discussed in more detail in the following sections.

3.2 Basic approaches

Over the last years a large number of global, continental, national and regional emission inventories of air pollutants have been developed. Two major approaches that have been used in these studies can be distinguished:

- In the **'bottom up'-approach** total emissions of a specified area over a specified time span are compiled by aggregation of individual emission accounts for all emission sources under consideration. Data at the plant level is either collected through permanent monitoring of the emission fluxes or calculated based on actually reported activity levels of the emission sources (i.e. the quantity of the individual emission generating activities) and the appropriate emission factors (the average amount of emissions per unit of activity).

- In contrast to this, the **'top down'-approach** computes emission levels of a region based on aggregated statistical information by applying emission factors that should reflect the average characteristics of the entire stock of emission sources.

Both approaches have been applied in the past, and at the moment a final judgement on the quality of results seems to be rather difficult. The 'bottom up'-approach appears as most appropriate for the major point sources of emissions for which reliable monitoring data exist. However, the accuracy of overall results of a bottom-up inventory depends crucially on the complete coverage of all emission sources and in reality relevant measurements or even statistical data on activity rates are rarely available for the entire stock of plants in a particular region. Such a complete recording, however, is often the advantage of the 'top down'-procedure, at least if the statistical information is comprehensive. Uncertainties are introduced through the selection of the average emission factors.

Widely used inventory systems, such as the CORINAIR system applied for the Member Countries of the European Communities (CEC, 1991; CORINAIR, 1990) or the NAPAP emission inventory for the U.S.A. (NAPAP, 1990), employ a combination of both approaches. Emissions from large point sources - if they are known - are compiled using the 'bottom up'-approach, whereas emissions from area sources, e.g. from households or transport, are estimated with the 'top down'-approach. This procedure has the advantage that data from large emission sources are documented in more detail and are related to the individual sources, which is of importance for any priority ranking of measures to reduce air pollution.

For estimating emissions from urban areas in developing countries it is recommended to adopt a combination of the top-down and the bottom-up methodologies. Such an approach matches the major requirements for strategic decisions for reducing air pollution best by providing reliable data on overall emissions, as well as information on the largest single sources.

3.3 Accuracy and uncertainties

Significant uncertainties are inherent in all approaches to derive estimates of quantities of emissions of air pollutants. Several studies have been undertaken to quantify uncertainties of emission estimates and to identify the most sensitive input data and parameters (Baars, 1990; Benkovitz and Oden, 1987; Egglestone, 1989). These studies list the following items as major sources of uncertainties:

- The **completeness** of the inventories, i.e. that all relevant emission sources are covered by the inventory. Experience shows that in some cases major source categories have been omitted from consideration in the past.

- The accuracy of the **statistical base information** available. In many cases the statistical data required for the envisaged inventory were not available with the necessary spatial, sectorial or temporal resolution.

- The reliability of the **emission factors**. Emission factors are usually derived from a small number of measurements and extrapolated to other emitters with similar technical properties. However, there are considerable uncertainties associated with many monitoring results and the extrapolation of emission factors to other emission sources adds an additional element of uncertainty. As experience (e.g. with the CORINAIR system) shows, emission factors even for the same production processes may vary by up to a factor of ten.

The studies suggest that once the pioneering phase of inventory techniques is overcome, the uncertainties introduced by possible omission of emission sources and unreliable statistical information should be of limited importance. Uncertainties associated with emission factors, however, may have a considerable impact on the reliability of the final result (e.g. national total emissions). Egglestone estimates the uncertainty of total SO_2 emissions of the United Kingdom to be within the range of ± 10

percent, and of national NO_x emissions of ± 20 percent. For VOC emissions the uncertainties of the estimates are considerably larger than for NO_x (Egglestone, 1989).

It has to be noted that these analyses were undertaken for the situation in highly industrialized countries for which an established methodology of emission calculation has been available for many years and in which the quality of statistical information is generally considered as acceptable. The conclusions might change significantly as soon as less developed countries are studied. Still, the uncertainties introduced by inappropriate methodology of emission calculation can be limited by applying standard calculation routines which have been critically examined by international experts. The influence of limited access to, or lack of, required statistical information could easily outweigh the uncertainties introduced by standard emission factors.

It can be concluded that for the envisaged purpose, i.e. emission inventory tools for cities in less developed countries, not only the emission factors used for calculation but also the quality of statistical base information does need special attention. Furthermore, the question arises whether the inevitable uncertainties introduced by these factors might not suggest a simplified estimation procedure to derive a rough emission estimate with relatively little effort. It seems promising, however, to supplement such simplified approaches with a special uncertainty analysis to derive also quality measures of the results. Several methods for such uncertainty analysis have been suggested in the literature (e.g. Baars, 1990; Benkovitz, 1985). Once they are implemented in the general software package they do not increase the workload for the individual model user and uncertainty estimates could be derived on a routine basis.

3.4 Lack of information: Surrogate data

Experience shows that in many cases (not only in developing countries) the necessary statistics to calculate emission estimates are not always available. To enable at least an estimate of emissions an envisaged emission inventory tool should provide guidance to derive approximations of the required information based on readily available data. This includes hints on where relevant information can usually be obtained from, how to estimate data, for example, by providing ranges of typical values, and by suggesting various techniques to approximate the desired data (e.g. the use of surrogate data, which usually show a strong correlation to the missing piece of information). Such approaches have been implemented in various inventories in many industrialized countries and must be adapted accordingly to match the specific situation of developing countries. The use of such techniques will greatly facilitate the actual use of the emission inventory tool even in difficult situations.

3.5 The spatial disaggregation

Since the location of emission sources is relevant, not least to estimate impacts of air pollution, the spatial component is an important element of many emission inventory systems. Several techniques are available to allocate emissions with a fine spatial resolution even in cases where the primary information on the location of all emission sources is not available.

Following the conclusions of the preceding paragraphs, emissions from large point sources should be compiled on a plant level. The inclusion of the geographical location of the emitter into the data base seems a logical extension and will serve all potential demands arising from possible air quality modeling studies.

Although methodologies to spatially allocate emissions from area sources are available (e.g. distributing emissions from households over several regions in proportion to the population) it seems questionable whether for urban areas the additional efforts to derive this information are in balance with the gain in additional information. It is therefore recommended to exclude the spatial allocation of area sources within an urban region from the first analysis and focus efforts on more important problems.

3.6 The emission inventory system as part of a comprehensive tool to develop cost-effective emission reduction strategies

As analyzed above, the major goal of an inventory tool should be to facilitate the estimation of (annual) emissions of several substances for a recent year. This information is relevant in order to assess the levels of ambient air quality in cities and to derive priority statements for measures to reduce air pollution. The derivation of such priority rankings, taking into account the specific dispersion behavior of emissions, differences in costs of potential emission reductions and variations in environmental sensitivities (or population densities), can be supported by formalized methods.

Currently, there are several methodologies available to model local dispersion behavior of pollutants. The suggested emission inventory tool could, therefore, in an eventual later phase of development, be supplemented by a standardized module to analyze urban air quality, which could be easily adapted to local conditions. The inventory system as proposed in this study will provide an important piece of information also for dispersion modeling. Additional information will be necessary on the spatial distribution of area sources. Methodologies exist that allow for the spatial allocation of aggregated data (such as that resulting from the described inventory data base) with the help of surrogate data (such as population densities, energy consumption, etc.). If required, such methods could be incorporated into the inventory system at a later stage.

If episode modeling (e.g. for smog episodes) is of interest, emission data must also be desegregated temporarily. An international project to develop techniques to perform temporal disaggregation of emissions began recently within the GENEMIS activities in Europe. Expected outcomes of this project could also be introduced in this inventory system at a later stage.

The growth dynamics of many cities in developing countries leads to an interest in future emission levels. Since total emissions are determined both by the emission factors, i.e. depending on the type of technology, as well as on anthropogenic activities, any expected future increase in the volume of activities will also result in a growth of emissions unless countermeasures are taken. The processes influencing general economic growth are rather complex and several model approaches try to simulate future development. It seems therefore interesting to link an inventory system describing the present or recent status of emissions with such models in order to predict future emission levels.

As an example, the LEAP model developed at the Boston branch of the Stockholm Environment Institute simulates inter alia trends in urban energy consumption and estimates future rates of energy related emissions. The LEAP model is linked with an environmental data base (EDB) containing emission factors for energy-related activities with a special focus on developing countries (SEI, 1990). A linkage of the LEAP model with an implementation of the emission inventory system seems promising to improve the quality of emission estimates of the LEAP model, extend the emission estimates of the model from its current limitation on combustion activities to other sources, and could simultaneously help to identify relevant future sources of pollution. Such a linkage is rather simple to perform, as long as the sectorial aggregation of the inventory system and the model is consistent. Before taking decisions on the final sectorial aggregation of emission sources it seems worthwhile to harmonize the data structure with, e.g., the LEAP model.

Such elements can be combined to enable the **integrated assessment** of emission reduction strategies. Data on emission generating activities should ultimately be linked with data bases on emission control measures (including information on economic aspects of emission controls such as costs of alternative control technologies, etc.) and with tools to simulate the dispersion of emissions in the atmosphere. Finally, the resulting exposure levels should be compared with the various areas of potential damage, e.g. human health. Thereby, cost-effective measures to reduce negative impacts of air pollution can be analyzed. Such approaches of integrated assessment have been implemented, e.g. for transboundary air pollution (see Alcamo et al., 1990), and have proven most successful in supporting the optimal allocation of limited resources for emission reductions. A similar methodology for the assessment of urban air pollution, although not supported by computer facilities, has been suggested by the WHO (WHO 1989).

It should be mentioned that for all these additional elements, which allow an integrated assessment of emission reduction strategies, emission inventories are an essential component. The relevance of the entire assessment is crucially related to the quality of the emission data base.

3.7 Conclusions

Summing up, the following conclusions can be considered as most important to enable a wide application of the emission inventory system:

- *The envisaged emission inventories should primarily provide information for strategic decisions to reduce urban air pollution. For this, accurate information on the major emission sources is necessary.*

- *A combination of the bottom-up approach (for large point sources) and the top-down approach (for area sources and smaller point sources) is recommended to achieve results with reasonable efforts.*

- *In the light of the most likely limited availability of statistical data as well as of appropriate emission coefficients, a careful balance of the efforts devoted to the collection both of statistics and of emission factors could reduce the work required while keeping a certain level of accuracy of the overall results. This means that efforts should not proceed too far, e.g. on* *finding the most accurate statistics, as long as the available emission factors are of limited quality.*

- *Within an initial effort to establish urban emission inventories the spatial disaggregation of area emissions (from small sources) is of lower relevance. The emphasis of the work should focus on overall completeness and on quantitative accuracy.*

- *The ability to utilize widely available, reliable standard computer hardware (i.e. personal computers) is of crucial importance to achieve widespread dissemination and successful application of the software package in developing countries.*

- *User-friendly guidance through the system and application of expert system techniques is essential to facilitate the actual application.*

- *A modular structure of the entire software system should provide the possibility for eventual updates to introduce recent research results.*

To promote a widespread application of such a system in developing countries and to maximize the results to be obtained with a limited amount of resources it seems beneficial to keep the system as simple as possible for the individual user. Careful design of the user's interface and application of state-of-the-art techniques to compute emissions can guarantee a certain quality of the results in individual applications.

4. Emission inventory components

4.1 Pollutants

Any inventory system will represent a compromise between completeness, for example in terms of pollutants considered by the inventory, and the efforts required to compile the necessary input. Basically, the inclusion of more pollutants requires more work. However, as will be shown, this principle does not fully apply in all cases. Many anthropogenic activities emit more than one pollutant simultaneously, thus synergism can be expected in compiling multi-pollutant inventories. It will be shown that the efforts required by the prospective user to establish a particular inventory grow less than proportional with the number of pollutants considered. Unfortunately, the development time for creating the software system itself does not follow this rule since separate calculation routines have to be implemented for each pollutant individually.

As discussed in the previous section emission inventories should preferably be oriented towards actual environmental problems. Table 4.1 lists the related environmental problems and the geographical scale of effects for the major pollutants. If urban air quality is considered (local scale), elevated ambient concentrations of air pollutants mainly have negative impacts on human health and vegetation, with emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), non-methane volatile organic compounds (NM-VOC), particulate matter (TSP) and lead (Pb) as the most prominent contributors. According to the above established principle, urban inventories should therefore primarily focus on these pollutants.

The third column of Table 4.1 indicates that many pollutants contributing to local impacts may also have significant effects on meso-scale environmental problems (acidification of soils, lakes and groundwater, eutrophication, tropospheric ozone formation, etc.). In order to establish a comprehensive inventory of the sources contributing to these problems, in addition to the substances mentioned above, knowledge of ammonia emissions (NH_3) would also be necessary. Whereas in developed countries urban emissions of ammonia (mainly resulting from agricultural activities) are of lower importance, farming activities in cities in developing countries might result in non-negligible emissions from this source.

Emissions of carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) are prominent greenhouse gases, but do not directly contribute to local or regional air quality problems. However, international obligations to report the levels of greenhouse gases emissions and to control them might suggest also including these pollutants into a comprehensive inventory system.

As mentioned above the efforts required to compile an actual inventory of a region are less related to the number of pollutants considered but are strongly influenced by the variety of different activities generating the individual emissions. Table 4.2 displays the major source categories (activities) for the individual pollutants listed in Table 4.1.

Table 4.1: Major environmental problems caused by individual primary pollutants, and priorities of the GEMS/AIR activities

Pollutant	Scale: local	Scale: meso-scale	Scale: global	GEMS/AIR priorities
SO_2	health, vegetation, material	acidification		x
NO_x	health, vegetation	acidification, eutrophication, tropospheric ozone		x
CO	health, vegetation			x
NM-VOC	health, vegetation	tropospheric ozone		
CO_2			climate	
N_2O			climate	
NH_3		eutrophication, acidification		
CH_4			climate	
TSP	health	acidification		x
Pb	health			x

Table 4.2: Major source categories and their relevance for air pollution.

	SO_2	NO_x	CO	NMVOC	CO_2	N_2O	NH_3	CH_4	TSP	Pb
Public power generation	xxx	xxx	x	x	xxx	xx	(x)	x	xxx	-
Commercial, institutional and residential energy combustion	xxx	xxx	xxx	xxx	xxx	x	-	xx	xxx	-
Industrial energy combustion	xxx	xxx	x	x	xxx	x	(x)	x	xx	-
Non-combustion processes	x	x	x	x	xx	x	(x)	x	x	x
Extraction and distribution of fossil fuels	x	x	x	xxx	xx	x	-	xxx	x	-
Solvent use	-	-	-	xxx	-	-	-	-	-	-
Road transport	x	x	xxx	xxx	xxx	xx	x	xx	x	xxx
Waste treatment and disposal	x	x	xxx	xx	xx	x	xx	xx	x	-
Agriculture	-	-	-	xx	-	xxx	xxx	xxx	-	-
Nature (excl. volcanoes)	-	-	x	x	x	xxx	(x)	xx	x	-

The signs (xxx, xx, x, -) indicate the importance of the emission source to the overall emissions.

If an inventory is limited to SO_2 and NO_x only, emissions from energy combustion (in power stations, industry, traffic and the domestic and commercial sectors), industrial non-combustion processes, and from waste treatment and disposal are of highest importance. If carbon monoxide, ammonia and particulates are of interest, agricultural activities and some natural sources also have to be included in the inventory. Inventories of non-methane VOC emissions also require the incorporation of solvent use, and the extraction and distribution of fossil fuels. Assuming appropriate emission factors and calculation routines are provided for by the software package, a full coverage of anthropogenic activities of all other pollutants listed in Table 4.2 can be calculated without major effort.

Table 4.3 lists the relationship between the pollutants considered and activities to be covered in the system. The table shows that, if only SO_2, NO_x and Pb are considered, the emission inventory can be limited to energy combustion, industrial activies, traffic) and waste treatment. If CO, NH_3 or TSP are to be included, the inventory has to cover also agricultural activities and natural sources. Consideration of greenhouse gas emissions, however, does not require major additional activities to be quantified by the prospective user.

Table 4.3: Relationship between pollutants and group of activities to be considered

Activities to be quantified by the user	Pollutants			
	SO_2, NO_x, Pb	CO, NH_3, TSP	NM-VOC	CH_4, CO_2, N_2O
Energy combustion, industrial processes, transport, waste treatment	X	X	X	X
Agricultural activities, natural sources		X	X	X
Solvent use, fuel distribution			X	X

Methodologies to derive estimates of emission releases for most of the pollutants contained in the tables are available and implemented in various emission inventory systems, e.g. the CORINAIR system. Problems arise, however, in estimating emissions of particulates and dust (TSP). A large variety of dust emission sources exists, but only a part of them is directly related to the activities listed in Table 4.2. Additional important sources, in particular in developing countries, might be dust from the land surface (depending on the land use), from roads, from production processes (e.g. mining and quarrying), and from material handling (e.g. transport of goods, loading and unloading in harbors, etc.). Information in the literature on emission factors for these activities is scarce and even an estimate of the magnitude and composition of such emissions seems to be rather difficult. If these emissions are to be included into an inventory system (and environmental and health impacts caused by dust would definitely justify this), substantial analysis on relevant emission sources and appropriate emission factors, including the physical size of the particles, will be necessary.

4.2 Emission generating activities

The existing tools for emission inventories, such as the CORINAIR system, contain standard methodologies to compute emissions for all the pollutants listed in Table 4.1 with the exception of TSP and lead. In a first approach, these techniques could also be used for estimating urban emissions in developing countries. If data is not compiled with the bottom-up approach (i.e. using actual monitoring results), emissions are calculated according to Equation 1 as a product of the activity rate and an appropriate emission factor. In order to take the specific emission properties of individual activities into account, the activity groups as listed in Table 4.2 are desegregated into a large number of detailed subsectors for which rather homogeneous emission factors are applicable.

$$\textit{emissions} = \textit{activity} * \textit{emission factor} \qquad (1)$$

Emission inventory systems usually contain a standard list of emission generating activities. The activities contained in these lists depend, *inter alia*, on the purpose of the inventory, the pollutants considered and not least on the information available at the time the system is developed. The table in Annex 1 lists the emission generating activities considered by the CORINAIR inventory (the 'SNAP 90'-code). This list reflects the current 'state of the art' of emission accounting and is similar to the emission generating activities considered in other relevant inventories (such as WHO, 1989; the EPA inventory and the NAPAP inventory of the United States.)

In the CORINAIR system three levels are distinguished. Level 1 (indicated by the one-digit code) serves as a standardized reporting format for aggregated data. Level 2 (two digits) describes the major activities (aggregated e.g. to industrial branches) and Level 3 lists the individual emission generating activities.

In the ideal case an inventory is compiled based on information at aggregation Level 3. User-supplied activity data is combined with emission factors, which are - again in the ideal case - specified by the user. In those cases where no information on appropriate emission factors is available, the software package should provide a data base with default emission factors that have been compiled by international expert groups. For some of these factors, procedures could be implemented that adapt the values to those local conditions having an important influence, e.g. by taking into account the temperature dependence of emission factors or driving cycles typical in a country.

It should be mentioned that Annex 1 provides the latest information on relevant emission sources for SO_2, NO_x, NM-VOC, NH_3, Pb and the greenhouse gases CO_2, N_2O and CH_4. However, the list is incomplete as far as emissions of particles are concerned. Implementation of an emission inventory tool for particles will require a special analysis of emission generating activities and appropriate emission factors.

4.3 A reduced set of emission generating activities

In many emission inventories significant uncertainties result from the use of uncertain emission factors. Actual measurements on which the selection of the proper emission factor could be based are rarely available, and thus emission factors applied in many inventories are usually taken from the literature or from general data bases. Process- and site-specific factors leading to lower or higher emissions are consequently often ignored.

One option to narrow down the range of possible emission factors is to distinguish a large variety of different emission generating activities, and apply a 'typical' emission factor for each individual option. By doing so, inaccuracies introduced by the inhomogeneous composition of activity groups can be reduced. The activities listed in the table of Annex 1 can be considered as one example of such a detailed disaggregation.

However, experience shows that in many cases the lack of statistical information prohibits the compilation of inventories at the detail of Level 3, even in industrialized countries (Klaassen and Amann, 1991). Most likely similar situations will occur in less developed countries. Consequently, in many cases the gain in accuracy introduced by a clear separation of activities will be outweighed by uncertainties due to inaccurate statistical information on the individual activity levels.

Thus, when estimating urban emissions in developing countries, it does not seem worthwhile placing too much emphasis on the elaboration of appropriate emission factors as long as the statistical base information is sparse. In addition, the necessary expertise to determine the most accurate emission factors will probably not be available locally. As far as possible, use should be made of default emission factors (defined by experts). Refined methodologies to determine emission factors should only be applied for the most influential activities that contribute large shares to total emissions.

Keeping these difficulties in mind, a methodology to estimate emissions on a more aggregated level for the specific situation in developing countries seems promising. A rough estimate of emissions is possible also on Level 2, applying average emission factors for aggregated activity groups. The table in Annex 2 gives an example of a simplified data structure for which only limited information is necessary. (Note that the list is incomplete as far as activities generating TSP emissions is concerned!)

Whereas a first estimate could be based on the simplified data structure outlined in Annex 2, it would still be beneficial to incorporate the full list of activities contained in Annex 1 into the software package for two reasons:

- Annex 1 provides a rather complete coverage of emission generating activities. Supported by specific expert systems techniques such a full list will be useful for reference purposes and to inform the system user on potential emission sources. Thereby, the incorporation of Annex 1 into the software package will strengthen the educational character of the inventory tool substantially.

- The full list of activities might facilitate the identification of large point sources, in particular in the industrial sector, and enable an easy assessment of the potential contribution of individual sources to overall air pollution in a region. Also, it provides a consistent frame to incorporate more details on the most important emitters.

4.4 The selection of emission factors

The computer supported emission inventory tool will combine the data base on emission generating activities with emission factors to derive quantities of emissions of a specific region. Whereas in the ideal case emission factors should be user-supplied, in reality only very few users will have the expertise to define appropriate parameters. The software tool should therefore provide a set of default emission factors that can be modified by special calculation routines to take into account local conditions such as temperature, age structure of emission sources, typical driving cycles in a region, etc.

The compilation of an all-purpose set of default emission factors is a rather ambitious and probably never ending task. In order to derive practical solutions, a compromise between the achievable accuracy and efforts used for the analysis will have to be made.

A number of data bases on emission factors exist, *inter alia*, the EPA guidelines to derive emission estimates (US-EPA, 1986), the WHO compendium (WHO, 1989) and the CORINAIR emission factor handbook (Bouscaren, 1992). A number of energy models also contain rather comprehensive information, such as the LEAP/EDB model (SEI 1990).

It is suggested that the first phase of the emission inventory tool development should analyze and screen the emission factors available in the literature, study the applicability of these factors to the specific situation in developing countries and organize an international peer review to discuss the most critical data. The compilation of emission factors for emissions of particles also needs special attention.

4.5 Conclusions

For the purpose of developing an easy-to-use system to inventory emissions from urban areas in developing countries the following conclusions can be drawn from this section:

- *The major goal of an emission inventory tool should be the achievement of overall completeness of the inventory rather than the superficial accuracy of some detailed data on some emission sources while data on other source categories is lacking. Therefore, in the case* *of missing data, emphasis should be focused on aggregated estimates to derive rough, but complete estimates.*

- *Limited availability of statistical information suggests that the primary focus of the inventory system should be at the aggregated level. Annex 2 could serve as a basic list of the major activities to be considered by the system.*

- *It is important to include the full list of emission generating activities in the system as an option to consider more details of locally important emission sources, and as a reference base for the latest knowledge on emission inventorying.*

- *Special routines should keep the consistency of the overall data base (e.g. on Level 2) if detailed (and possibly incomplete) information is included on a deeper level.*

- *As a basic rule, emission factors should be user-specified. The inventory tool must however provide a set of default emission factors that could be used in the absence of more detailed information.*

- *Default emission factors can be derived from several publications and data bases. A careful review is necessary to select factors representative for the conditions in developing countries. This review could be organized most efficiently within an international expert workshop on emissions from developing countries.*

5. The implementation of the tool

5.1 Expert system techniques

One of the most important objectives of the envisaged emission inventory tool is its educational function to transfer knowledge on emission generating activities to developing countries. Whereas the preceding chapter discussed the data base to be established for a comprehensive assessment of emissions from a specific region, this section will deal with those elements that facilitate the easy use of the software package even for inexperienced users. This educational component will make the suggested system a unique tool for capacity building in developing countries.

Existing software tools to estimate emissions from a specific region combine technical knowledge (e.g. default emission factors) with user-provided input. The user interface of current tools, however, is designed for more experienced experts who have a substantial knowledge of emission inventorying. This assumed requirement will often not be available in developing countries, and the existing tools do not provide sufficient support for less experienced personnel.

Expert systems, an emerging technology in information processing and decision support, are becoming increasingly useful tools in numerous application areas. Expert systems are man-machine systems that perform problem-solving tasks in a specific domain. They use rules, heuristic and techniques to represent knowledge, together with inference mechanisms, in order to derive or deduce conclusions from stored and user-supplied information.

Application- and problem-oriented systems are often hybrid or embedded where elements of artificial intelligence (AI) technology are combined with the more classical techniques of information processing. Here, traditional numerical data processing is supplemented by symbolic elements, rules and heuristic.

The task analyzed in this study is a typical case where the addition of a small amount of 'knowledge' in the above sense to an existing framework can considerably extend its power and usefulness and at the same time make it much easier to use. Clearly, a system that 'knows' about the limits of its applicability, what kind of input data it needs, how to estimate its parameters from easily available information, how to structure its inputs, perform the calculations and interpret its outcomes, requires less technical expertise of the user and also assists the user with domain expertise in the application area.

Application of expert systems techniques would guide the user through the creation of the application-specific individual data base of activity rates, both on Level 2, with possible suggestions from where to derive relevant data, on Level 3 it would provide technical information on the individual activities (major types of processes, criteria to select the appropriate emission factor, software supported modifications of emission factors, etc.).

For many years expert systems required the use of expensive advanced computer technology. Over the last few years, however, approaches have been developed to enable the utilization of such techniques on generally available computer hardware (i.e. advanced personal computers), although sometimes with a reduced set of facilities.

Clearly the benefits to be gained by the prospective users have their price. The introduction of expert system techniques into an emission inventory tool requires not only substantial efforts in developing the software but also, and probably even more so, in the formulation of the specific knowledge base to be incorporated into the system. However, the additional efforts invested in the design of a more sophisticated package, including the expert's knowledge, will definitely facilitate final application of the tool and allow for transfer of the latest information on emission inventory techniques to developing countries, thereby ultimately producing important environmental information from many different cities all over the world.

5.2 The user interface

Another central prerequisite to facilitate the operation of the system over and above the application of expert systems techniques, is the utilization of modern techniques for interactive use of the package. In particular, the system should be interactive and completely menu-driven to guide the novice user with appropriate prompts and menu options. All required user input should be pre-defined by the system as a set of options the user can choose from. Thus, it should not be necessary for the user to learn a special command language to use it effectively.

Extensive help in the form of explanation text screens should be available both as an on-line manual to explain the operation of the system, as well as to provide information on the basics of the subject of emission inventories.

5.3. Software compatibility

Although it can be expected that UNIX-based operating systems will gain market shares in the PC segment in the future and that eventually new operating systems could emerge, it seems beneficial to design the inventory system for the standard MS-DOS operating environment. Although MS-DOS might not be the best and most advanced system, it has reached a market position wherebey it is unlikely to disappear in the near future. Also, in order to provide compatibility with MS-DOS applications, other systems that might potentially replace MS-DOS will have an option to simulate the

MS-DOS environment or run MS-DOS programs as subtasks. Therefore, the decision to develop the software package for a DOS environment will minimize the problems of portability and can guarantee the highest chance for keeping it operational for quite some time in the future.

A more difficult question is whether the software package should make use of facilities provided by the MS-WINDOWS system. MS-WINDOWS provides a common user interface for all programs running under MS-WINDOWS; therefore, the learning time for new programs for the individual user already familiar with MS-WINDOWS will be reduced. In addition, MS-WINDOWS offers useful options for connecting different types of printers, plotters, etc. The major disadvantage of MS-WINDOWS is that it requires a substantial amount of computer core memory (at least 4 MB), something not all machines have. Another disadvantage is that programming under MS-WINDOWS (i.e. development of the software package) requires special expertise not available everywhere at the moment. One solution may be to leave this decision to the contractor actually developing the software.

It has proven useful that internal data storage comply with the standards of commercial data base software. Access to data files and information handling, including updating data and adding new information possibly emerging from a linkage to other models, etc., could then be easily performed with commercially available software. If the software package is intended to be implemented on DOS operated personal computers, adherence, e.g., to the widely used DBASE data structure is highly recommended.

5.4 Hardware considerations

The hardware configuration chosen to implement the emission inventory system will have a crucial impact on the potential for disseminating the software package. Experience at IIASA shows that software that can be operated on PC has a wide range of potential users (e.g. nearly 150 copies of the PC-based RAINS model on acidification in Europe have been distributed) whereas software requiring more advanced computer hardware has a much smaller group of clients. The widespread availability of personal computers, as well as their robustness to work also under unfavorable (e.g. climatic) conditions, are strong arguments why an emission inventory tool for developing countries be operational on such basic computer hardware.

Naturally, not everything that is possible with advanced computers can also be implemented on personal computers, in particular as far as graphical displays and expert systems techniques are concerned. However, if wide application of the tool is an objective, a reasonable compromise promoting advanced PC hardware and basic expert systems techniques to facilitate the use of the package can most probably achieve the envisaged dissemination.

At present, personal computers with 386 processors and VGA graphics display are already widely available in many countries and it can be expected that in a few years, when the software package is ready, such a configuration will be considered as the minimum standard even within local authorities in developing countries. Should such equipment not be available, the expected decline in the price of such configurations, from currently somewhat below 2500 US $, should enable their acquisition without major problems. The performance of such machines is sufficient to carry out the tasks described in this paper at a reasonable speed and also the use of expert systems packages will not overdemand the machines.

5.5 Training demand and user's support

In order to derive the most reliable results from an emission estimation exercise it is absolutely necessary to provide extensive training to prospective users. A proper introduction to the software package consists of three major elements:

- The application of expert systems techniques, including a thorough generation of the knowledge base supporting emission inventory activities to ensure that users are always aware of what they are currently doing. Major attention should also be devoted to a careful design of the interactive user's surface (including on-line help facilities), to ease the actual use of the software package. This task is a one-time investment during the development phase and increased efforts devoted to these aspects will reduce difficulties in familiarizing the individual users of the system later on.

- The preparation of a comprehensive user's manual. Although on-line help facilities are important to guide the user through the system, hard-copy manuals prove most useful in decreasing the initial difficulties of getting accustomed to a software package. Hard-copy manuals are a valuable reference tool for any problems occurring during operation and are sometimes easier to use than on-line help facilities. Experience shows that compiling a system manual with a comparable complexity requires significant time and should be a separate item in the work contract for software package development.

- Although expert systems techniques, interactive user's surface and manual are important elements to facilitate use of a software package, special training sessions for novice users are extremely important and an efficient approach to quickly familiarize people with the system. IIASA's experience with the RAINS model and the CORINAIR software system suggests that even complete newcomers can best acquaint themselves within three to five days with the basics of such software systems in training sessions attended by up to ten people. It is important that such training sessions, supervised by an experienced expert who has been involved in the development of the system, provide on-line computer facilities for all participants. For the specific task of training inexperienced staff it might prove useful not only to focus on the use of the software package, but also lecture the basic principles and methods of emission accounting.

In conclusion, therefore, there exists a trade-off between the efforts devoted to the development of the system (expert systems techniques, user's surface, help facilities, manual) and the time required to familiarize the individual user with the system.

5.6 Conclusions

Any implementation of an emission inventory tool for developing countries should take account of the following aspects:

- *In order to achieve a wide dissemination of inventory activities it is essential that the implementation and the operation of the software package is suitable for less experienced staff.*

- *Properly designed expert systems techniques can greatly facilitate the use of the system and will have an important educational function in the transfer of knowledge on emission accounting to developing countries. The additional resources required for the application of expert systems techniques during the development phase, in particular the creation of the knowledge base specific for emission inventories, will ultimately prove to be an efficient* *investments for the wide dissemination of the emission inventory tool.*

- *Although the powerful graphics capabilities of advanced hardware systems such as workstations might seem more appealing, for example for producing attractive graphical representation of results, their limited availability in developing countries and the problems of actual operation under less favorable conditions have to be considered as major obstacles for a wide dissemination of an emission inventory tool operational on such equipment. It is strongly recommended to design the envisaged software package for generally available personal computers with standard configuration.*

- *In the same way it is recommended to maintain compatibility with major existing PC software applications, in particular by designing the inventory tool to be operational under the MS-DOS operating system.*

- *There exists a trade-off between the efforts devoted to the development of the system and the time required to familiarize the user with the system. Application of expert systems techniques, the careful design of the user's interface and the preparation of a comprehensive user's manual will considerably reduce the learning time for the user. Experience shows that proper application of such elements can reduce the training time to a few days.*

6. Requirements to develop an emission inventory tool

There exists a trade-off between the efforts put into the development and refinement of the software package and the time the individual user will need to get acquainted with the system, and to successfully establish an emission estimate. In the light of the limited knowledge in developing countries is seems beneficial to invest more into the development phase and obtain a package that can be easily applied to many cities.

Table 6.1 provides an estimate of the efforts and manpower required to produce a software package to support the estimation of emissions in cities in developing countries for all pollutants listed in Table 4.3 This estimate is based on the assumption that basic emission factors can be extracted from existing data bases (e.g. from the CORINAIR, LEAP, WHO, etc.). Given the availability of such data bases special efforts have to be devoted to an analysis of the appropriateness of such data for the situation in developing countries.

Table 6.1: Estimated manpower requirements to develop the described system:

ACTIVITY	DESCRIPTION	EFFORTS
1. Detailed design	Detailed design of the menu structure of the system, the data storage, the application of expert systems techniques	2 person months
2.1 Emission factors	Compilation of default emission factors, adaptation for developing countries	5 person months
2.2 Emission factors workshop	International expert meeting to peer review emission factors	per diems, travel
3.1 TSP emissions	Analysis of the sources of TSP emissions, emission factors	2 person months
4.1 Knowledge base for the expert system	Creation of the emission-related knowledge base for the expert system	5 person months
5.1 Data base management	Create data base for the system	2 person months
5.2 Menu pages, implementation of calculation rules	250 menu screens on Level 3, 80 menu screens on Level 2, result tables	9 person months
5.3 Expert systems shell	Selection of the expert systems shell, linkage with menu system and data base	2 person months
5.4 Software testing		1 person month
Documentation, Manual	Compiling and type-setting	6 person months
TOTAL REQUIREMENTS		34 person months + workshop

7. Conclusions

The lack of knowledge of sources and amounts of air pollutant emissions is a major obstacle for the introduction of efficient control actions. Computerized software packages could serve as tools for

- establishing inventories of air pollutant emissions in data-poor environments, and
- for the transfer of know-how on the identification and evaluation of emission sources.

The feasibility study shows that, in principle, the development of a software package to support local staff in estimating emissions is feasible. However, the envisaged system should take account the following basic aspects, which seem of crucial importance for successful dissemination and use of the tool in developing countries:

- It is of utmost importance that the software be easy to use also by inexperienced persons. Provision of all calculation routines, a user-friendly interface and the use of standard DOS based computer hardware will be important elements for a successful dissemination of the tool.

- It is recommended that the source categories to be considered in the inventory should be based on existing emission inventory standards (such as the European CORINAIR system or the US-EPA accounting). These lists must be supplemented by activities important in developing countries (e.g open burning of wastes, etc.).

- Default emission factors should be taken from existing data bases (e.g. LEAP/EDB, CORINAIR, etc.), but their applicability for situations in developing countries be reviewed in an expert meeting.

- The inventory calculation routines should be supplemented by an expert system for providing alternative surrogate data and for interactive training.

- Routine uncertainty analysis should be incorporated. Such uncertainty analysis does not put an additional burden on the individual user of the emission inventory tool, but could greatly improve the accuracy of estimates by focusing attention on the most influential areas.

- There exists a trade-off between the efforts put into the development and refinement of the software package and the time the individual user will need to get acquainted with the system, and to successfully establish an emission estimate. It is strongly suggested to invest more into the development phase and obtain a package that can be easily applied to many cities.

- A rough estimate of the manpower efforts required to develop a comprehensive package which takes into account the aspects discussed in this paper is 34 person months of experts work.

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ANNEX 1: Emission generating activities:

Socio-economic activities considered by the CORINAIR inventory (SNAP 90 code)

SNAP-CODE	SOURCE CATEGORY	ACTIVITY, UNIT
	Public Power, Cogeneration and District Heating Plants	
1.1	**Public power and cogeneration plants**	
1.1.1	Combustion plants ≥ 300 MW_{therm}	Electricity production (by fuel), GJ/year
1.1.2	Combustion plants ≥ 50 and < 300 MW_{therm}	Electricity production (by fuel), GJ/year
1.1.3	Combustion plants < 50 MW_{therm}	Electricity production (by fuel), GJ/year
1.1.4	Gas turbines	Electricity production (by fuel), GJ/year
1.1.5	Stationary engines	Electricity production (by fuel), GJ/year
1.2	**District heating plants**	
1.2.1	Combustion plants ≥ 300 MW_{therm}	District heat production (by fuel), GJ/year
1.2.2	Combustion plants ≥ 50 and < 300 MW_{therm}	District heat production (by fuel), GJ/year
1.2.3	Combustion plants < 50 MW_{therm}	District heat production (by fuel), GJ/year
1.2.4	Gas turbines	District heat production (by fuel), GJ/year
1.2.5	Stationary engines	District heat production (by fuel), GJ/year
2	**Commercial, Institutional and Residential Combustion Plants**	
2.0.1	Combustion plants ≥ 50 MW_{therm}	Fuel consumption (by fuel), GJ/year
2.0.2	Combustion plants < 50 MW_{therm}	Fuel consumption (by fuel), GJ/year
2.0.3	Gas turbines	Fuel consumption, GJ/year
2.0.4	Stationary engines	Fuel consumption (by fuel), GJ/year
3	**Industrial Combustion Plants and Processes with Combustion**	
3.1	**Combustion in boilers, gas turbines and stationary engines**	
3.1.1	Combustion plants ≥ 300 MW_{therm}	
3.1.2	Combustion plants ≥ 50 and < 300 MW_{therm}	
3.1.3	Combustion plants < 50 MW_{therm}	
3.1.4	Gas turbines	
3.1.5	Stationary engines	
3.2	**Process furnaces without contact**	

(Process where flames and/or combustion gases are not in contact with other products)

3.2.1	Refinery processes furnaces	
3.2.2	Coke oven furnaces	
3.2.3	Blast furnaces cowpers	Fuel input (by fuel), GJ/year
3.2.4	Plaster furnaces	Fuel input (by fuel), GJ/year

3.3 Processes with contact

(Processes where flames and/or combustion gases are in contact with other products)

3.3.1	Sinter plants	Fuel input (by fuel), t/year
3.3.2	Reheating furnaces steel and iron	Fuel input (by fuel), t/year
3.3.3	Gray iron foundries	Fuel input (by fuel), t/year
3.3.4	Lead 1st smelting	Fuel input (by fuel), t/year
3.3.5	Zinc 1st smelting	Fuel input (by fuel), t/year
3.3.6	Copper 1st smelting	Fuel input (by fuel), t/year
3.3.7	Lead 2nd smelting	Fuel input (by fuel), t/year
3.3.8	Zinc 2nd smelting	Fuel input (by fuel), t/year
3.3.9	Copper 2nd smelting	Fuel input (by fuel), t/year
3.3.10	Aluminum 2nd smelting	Fuel input (by fuel), t/year
3.3.11	Cement	Fuel input (by fuel), t/year
3.3.12	Lime (including iron and steel and paper pulp industries)	Fuel input (by fuel), t/year
3.3.13	Asphalt concrete plants	Fuel input (by fuel), t/year
3.3.14	Flat glass	Fuel input (by fuel), t/year
3.3.15	Container glass	Fuel input (by fuel), t/year
3.3.16	Glass wool (except binding)	Fuel input (by fuel), t/year
3.3.17	Other glass	Fuel input (by fuel), t/year
3.3.18	Mineral wool (except binding)	Fuel input (by fuel), t/year
3.3.19	Bricks and tiles	Fuel input (by fuel), t/year
3.3.20	Fine ceramic materials	Fuel input (by fuel), t/year
3.3.21	Paper-mill industry (drying processes)	Fuel input (by fuel), t/year

4 <u>Non Combustion Processes</u>

4.1 Processes in petroleum industries

4.1.1	Petroleum products processing	Production, t/year
4.1.2	Fluid catalytic cracking - CO boiler	Production, t/year
4.1.3	Sulfur recovery plants	Production, t/year

4.1.4	Storage and handling of petroleum products in refinery	t/year

4.2 Processes in iron and steel industries and collieries

4.2.1	Coke oven (door leakage and extinction)	Production, t/year
4.2.2	Blast furnace charging	Production, t/year
4.2.3	Pig iron tapping	Production, t/year
4.2.4	Solid smokeless fuel	Production, t/year
4.2.5	Open hearth furnace steel plant	Production, t/year
4.2.6	Basic oxygen furnace steel plant	Production, t/year
4.2.7	Electric furnace steel plant	Production, t/year
4.2.8	Rolling mills	Production, t/year

4.3 Processes in non-ferrous metal industries

4.3.1	Aluminum production	Production, t/year
4.3.2	Ferro alloys	Production, t/year
4.3.3	Silicium production	Production, t/year

4.4 Processes in inorganic chemical industries

4.4.1	Sulfuric acid	Production, t/year
4.4.2	Nitric acid	Production, t/year
4.4.3	Ammonia	Production, t/year
4.4.4	Ammonium sulphate	Production, t/year
4.4.5	Ammonium nitrate	Production, t/year
4.4.6	Ammonium phosphate	Production, t/year
4.4.7	NPK fertilizers	Production, t/year
4.4.8	Urea	Production, t/year
4.4.9	Carbon black	Production, t/year
4.4.10	Titanium dioxide	Production, t/year
4.4.11	Graphite	Production, t/year

4.5 Processes in organic chemical industries (bulk production)

4.5.1	Ethylene	Production, t/year
4.5.2	Propylene	Production, t/year
4.5.3	1,2 dichloroethane (except 4.5.5)	Production, t/year
4.5.4	Vinylchloride (except 4.5.5)	Production, t/year

4.5.5	1,2 dichloroethane + vinylchloride (balanced process)	Production, t/year
4.5.6	Polyethylene Low Density	Production, t/year
4.5.7	Polyethylene High Density	Production, t/year
4.5.8	Polyvinylchloride	Production, t/year
4.5.9	Polypropylene	Production, t/year
4.5.10	Styrene	Production, t/year
4.5.11	Polystyrene	Production, t/year
4.5.12	Styrene butadiene	Production, t/year
4.5.13	Styrene-butadiene latex	Production, t/year
4.5.14	Styrene-butadiene rubber (SBR)	Production, t/year
4.5.15	Acrylonitrile Butadiene Styrene (ABS) resins	Production, t/year
4.5.16	Ethylene oxide	Production, t/year
4.5.17	Formaldehyde	Production, t/year
4.5.18	Ethylbenzene	Production, t/year
4.5.19	Phthalic anhydride	Production, t/year
4.5.20	Acrylonitrile	Production, t/year
4.5.21	Storage and handling of chemical products in chemical industry	Production, t/year

4.6 Processes in wood, paper pulp, food and drink industries & other industries

4.6.1	Chipboard	Production, t/year
4.6.2	Paper pulp (kraft process)	
4.6.3	Paper pulp (acid sulfite process)	
4.6.4	Bread	
4.6.5	Wine	
4.6.6	Beer	
4.6.7	Spirits	
4.6.8	Bark gasifier (drying process)	
4.6.9	Asphalt roofing materials	

4.7 Cooling plants

5 <u>Extraction and Distribution of Fossil Fuels</u>

5.1 Extraction and 1st treatment of solid fossil fuel

5.1.1 Open cast mining

5.1.2 Underground mining

5.1.3 Storage of solid fuel

5.2 Extraction, 1st treatment and loading of liquid fossil fuels (including flaring)

5.2.1 Land-based activities

5.2.2 Off-shore activities

5.3 Extraction, 1st treatment and loading of gaseous fossil fuels (including flaring)

5.3.1 Land-based desulfurization

5.3.2 Land-based activities (other than desulfurization)

5.3.3 Off-shore activities

5.4 Liquid fuel distribution (except gasoline distribution)

5.4.1 Marine terminals (tankers, handling and storage)

5.4.2 Other handling and storage

5.5 Gasoline distribution

5.5.1 Refinery dispatch station

5.5.2 Transport and depots (except 5.5.3)

5.5.3 Service stations (including refuelling of cars)

5.6 Gas distribution networks

5.6.1 Pipelines

5.6.2 Pipeline compressor stations (gas turbines)

5.6.3 Distribution networks

6 Solvent Use

6.1 Paint application

6.1.1 Paint application: manufacture of automobiles

6.1.2 Other industrial paint application

6.1.3 Paint application: construction and buildings

6.1.4 Paint application: domestic use

6.2 Degreasing and dry cleaning

6.2.1 Metal degreasing

6.2.2 Dry cleaning

6.3 Chemical products manufacturing or processing

6.3.1 Polyester processing

6.3.2 Polyvinylchloride processing

6.3.3 Polyurethane processing

6.3.4 Polystyrene foam processing

6.3.5 Rubber processing

6.3.6 Pharmaceutical products manufacturing

6.3.7 Paints manufacturing

6.3.8 Inks manufacturing

6.3.9 Glues manufacturing

6.3.10 Asphalt blowing

6.3.11 Adhesive tapes manufacturing

6.4 Other use of solvents and related activities

6.4.1 Glass wool enduction

6.4.2 Mineral wool enduction

6.4.3 Printing industry

6.4.4 Fat, edible and non edible oil extraction

6.4.5 Application of glues and adhesives

6.4.6 Preservation of wood

6.4.7 Underseal treatment of vehicles

6.4.8 Domestic solvent use (other than paint application)

6.4.9 Vehicles dewaxing

7 <u>Road Transport</u>

7.1 Passenger cars

7.1.1 Highway driving

7.1.2 Rural driving

7.1.3 Urban driving

7.2 Light duty vehicles < 3.5 t

7.2.1 Highway driving
7.2.2 Rural driving
7.2.3 Urban driving

7.3 Heavy duty vehicles > 3.5 t and buses

7.3.1 Highway driving
7.3.2 Rural driving
7.3.3 Urban driving

7.4 Mopeds and motorcycles < 50 cm^3

7.5 Motorcycles > 50 cm^3

7.5.1 Highway driving
7.5.2 Road driving
7.5.3 Urban driving

7.6 Gasoline evaporation from vehicles

8. <u>Other Transport</u>

8.1 Off road vehicles and machines (including on road moving)

8.1.1 Agriculture
8.1.2 Forestry
8.1.3 Industry (quarries, roadwork, etc.)
8.1.4 Military

8.2 Railways

8.3 Inland waterways

8.4 Maritime activities

8.4.1 Harbors
8.4.2 National sea traffic
8.4.3 National fishing

8.5 Airports (LTO cycle and ground activities)

9. <u>Waste Treatment and Disposal</u>

9.1 Waste water treatment

9.2 Waste incineration

9.2.1 Incineration of domestic or municipal wastes
9.2.2 Incineration of industrial wastes (except flaring)
9.2.3 Flaring in oil refinery
9.2.4 Flaring in chemical industries
9.2.5 Incineration of sludge from waste water treatment

9.3 Sludge spreading

9.4 Land filling

9.5 Compost production from waste

9.6 Biogas production

9.7 Open burning of agricultural wastes

9.8 Latrines

10. <u>Agriculture</u>

10.1 Cultures with fertilizers

10.1.1 Permanent crops
10.1.2 Arable land crops
10.1.3 Rice field
10.1.4 Market gardening
10.1.5 Grassland

10.2 Cultures without fertilizers

10.2.1 Permanent crops
10.2.2 Arable land crops

10.2.3 Rice field

10.2.4 Market gardening

10.2.5 Grassland

10.3 Stubble burning

10.4 Animal breeding (enteric fermentation)

10.4.1 Bovines

10.4.2 Ovines

10.4.3 Pigs

10.4.4 Horses

10.4.5 Asses

10.5 Animal breeding (excretions)

10.5.1 Dairy cows

10.5.2 Other cattle

10.5.3 Fattening pigs

10.5.4 Sows

10.5.5 Sheep (including goats)

10.5.6 Horses (including mules and asses)

10.5.7 Laying hens

10.5.8 Broilers

10.5.9 Other poultry (ducks, geese, etc.)

11. <u>Nature</u>

11.1 Deciduous forests

11.1.1 High isoprene emitters

11.1.2 Low isoprene emitters

11.1.3 Non isoprene emitters

11.2 Coniferous forests

11.2.1 Pinus sylvestris

11.2.2 Other coniferous

11.3 Forest fires

11.4 Natural grassland

11.5 Humid zones (marshes - swamps)

11.5.1 Undrained and brackish marshes

11.5.2 Drained marshes

11.5.3 Raised bogs

11.6 Waters

11.6.1 Lakes

11.6.2 Shallow saltwater

11.6.3 Ground waters

11.6.4 Drainage waters

11.7 Animals

11.7.1 Termites

11.7.2 Mammals

11.8 Volcanoes

11.9 Near surface deposits

ANNEX 2: A reduced set of emission generating activities:

SNAP-CODE ACTIVITY:	UNIT
1. Public Power, Cogeneration and District Heating Plants	
Combustion: Production of electricity / by fuel	GJ/year
Combustion: Production of heat (district heating) / by fuel	GJ/year
Combined production of electricity & heat (district heat.) / by fuel	GJ/year
2. Commercial, Institutional and Residential Combustion Plants	
Combustion: Commerc., institut. & resid.(heat generation only) / by fuel	GJ/year
3. Industrial Combustion Plants and Processes with Combustion	
Oil refinery	t Crude/year
Combustion: Colliery / by fuel	GJ/year
Combustion: Primary iron & steel industry / by fuel	GJ/year
Combustion: Non ferrous metals industry / by fuel	GJ/year
Combustion: Chemical products industry / by fuel	GJ/year
Combustion: Paper and pulp production / by fuel	GJ/year
Combustion : Other industries / by fuel	GJ/year
Colliery coke production	t coke/year
Metallurgical coke production	t coke/year
4. Non-Combustion Processes	
Sinter plants	t product/year
Ferrous metal foundries	t product/year
Sulfuric acid production	t product/year
Nitric acid production	t product/year
Ethylene and propylene production	t product/year
1,2 dichloroethane production	t product/year
Vinyl chloride production	t product/year
Polyethylene low density production	t product/year
Polyethylene high density production	t product/year
Polyvinylchloride production	t product/year
Cement & lime production	t product/year

Glass production	t product/year
Production of ceramic materials	t product/year
Paper and pulp production	t product/year
Fermentation processes: bread production	t product/year
Fermentation processes: wine production	t product/year

6. Solvent Use

Paint application: manufacture of automobiles	cars/year
Paint application: ship building	capacity/year
Paint application: manufacture of metal articles	t product/year
Paint application: wood products industry	t product/year
Paint application: construction and buildings	Housings/year
Paint application: vehicles refinishing	cars/year
Paint application: domestic use	t paint/year
Use of domestic products	t product/year
Metal degreasing	t solvents/year
Dry cleaning	t solvents/year
Printing industry	t paper/year
Extraction of fat, edible and non edible oil	t product/year
Manufacturing and processing of chemical products (elastomers & rubber)	t product/year
Application of glues and adhesives	t products/year

7. Road Transport

Gasoline engines: automobiles & light duty vehicles / highway	km*vehicles/year
Gasoline engines: automobiles & light duty vehicles / road	km*vehicles/year
Gasoline engines: automobiles & light duty vehicles / urban	km*vehicles/year
Gasoline engines: heavy duty vehicles & autobuses > 3.5 t / highway	km*vehicles/year
Gasoline engines: heavy duty vehicles & autobuses > 3.5 t / road	km*vehicles/year
Gasoline engines: heavy duty vehicles & autobuses > 3.5 t / urban	km*vehicles/year
Gasoline engines: motor cycles < 50 cm^3	km*vehicles/year
Gasoline engines: motor cycles > 50 cm^3 / highway	km*vehicles/year
Gasoline engines: motor cycles > 50 cm^3 / road	km*vehicles/year
Gasoline engines: motor cycles > 50 cm^3 / urban	km*vehicles/year
Diesel engines: automobiles & light duty vehicles (< 3.5 t) / highway	km*vehicles/year
Diesel engines: automobiles & light duty vehicles (< 3.5 t) / road	km*vehicles/year
Diesel engines: automobiles & light duty vehicles (< 3.5 t) / urban	km*vehicles/year
Diesel engines: heavy duty vehicles & autobuses > 3.5 t / highway	km*vehicles/year
Diesel engines: heavy duty vehicles & autobuses > 3.5 t / road	km*vehicles/year

Diesel engines: heavy duty vehicles & autobuses > 3.5 t/ urban	km*vehicles/year
LPG engines : automobiles & light duty vehicles / highway	km*vehicles/year
LPG engines : automobiles & light duty vehicles / road	km*vehicles/year
LPG engines : automobiles & light duty vehicles / urban	km*vehicles/year
Depots of liquid fuels	t product/year
Service stations	t product/year

11. Nature

Coniferous forests	km^2
Deciduous forests	km^2
Natural grassland	km2
Forest fires	km2
Humid zones	km2
Waters	km2
Animals	
Other relevant natural activities (to define)	

Other Activities

Solid fossil fuels mining

Land filling

Sludge spreading

Distribution of gas