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Guidance on Estimating Non-point Source Emissions

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Prepared in co-operation with the Ministry of Housing, Spatial Planning and the Environment of The Netherlands

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Table of Contents

Introduction to the Document

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Countries around the world are adopting Pollutant Release and Transfer Registers to characterize the flows of specific chemical pollutants in the national environment. A Pollutant Release and Transfer Register (PRTR) is a database of releases and transfers of potentially harmful chemicals which includes information on the nature and quantity of such releases and transfers to air, water and land as well as waste transported to treatment and disposal sites. An important goal of a PRTR is to make pollutant release and transfer information accessible to those who may be interested and/or affected by it. As such, a PRTR is a tool for promoting efficient and effective policies for environmental protection and sustainable development.

A PRTR system generally covers releases and transfers from point sources of pollutants, such as industrial facilities. Pollutant emissions data from these point sources are usually obtained from information collected or generated at the facility level through direct measurement of emissions and transfers, or through the use of methods for estimating or calculating the emissions.[1] In addition to accounting for point sources of pollution, countries might also consider including in their PRTR systems the emissions contributed by non-point or diffuse sources of pollutants.

This document provides an introductory overview of methods to estimate pollutant emissions from non-point sources for national or regional pollutant inventories. It aims to inform PRTR designers on what methods and data requirements are entailed for the inclusion of non-point source emissions in a national PRTR system. **Part A** of the document is an introduction to non-point source emissions estimation. It explains some of the terminology used and outlines key issues with regard to the inclusion of non-point source emissions in a PRTR system. **Part B** introduces methods for estimating emissions from non-point and diffuse sources including: domestic activities and consumer product use; transportation and traffic; agriculture; small- and medium-sized enterprises; and natural sources. For each category, information is provided on the types of activities and pollutants typically involved, followed by an overview of the data needed and explanations of the available methods for estimating the emissions. Examples and simple calculations are provided throughout to illustrate the basic principles behind the estimation methods used and the types of data needed. **Part C** provides practical suggestions for determining whether and how to incorporate non-point source emissions into a PRTR, drawing upon the case example of The Netherlands. Part C also outlines some useful tools for estimating and making use of non-point source emissions data. A list of potentially valuable references for further information is provided in the **Annex** to the document.

[1] For an overview of methods for estimating emissions from industrial point sources of pollution, please refer to the UNITAR document entitled *Guidance for Facilities on PRTR Data Estimation and Reporting.* August 1998.

PART A: Introduction to Non-point Source Emissions Estimation

1. What Are Non-point or Diffuse Sources of Pollutants?

Non-point or diffuse sources of pollutants usually include emissions arising from agricultural activities, vehicular traffic, industrial activity of small- and medium-sized enterprises (SMEs), product use by consumers, among others. These non-point or diffuse sources of pollutants generally consist of a collection of individual and small scale polluting activities which for practical reasons cannot be treated as point sources of pollution in the emissions inventory.

The exact definition of what is considered a non-point or diffuse source within a PRTR is dependent on the purpose and scale of the emissions inventory. For an emissions inventory for a small town, for example, it may be possible to calculate or even measure emissions from every small industrial operation in the area, using statistical emission factors if necessary. However on a regional or national level, these small sources, for practical reasons, can only be treated as non-point or diffuse sources. For road traffic, measurements for every individual vehicle are not feasible on any level but a calculation for an individual road using traffic intensity and statistical emission factors is possible on all levels.

2. Why Consider Including Non-point or Diffuse Sources in a National PRTR?

In many countries, non-point or diffuse sources of pollutants represent a significant contribution to the total national emissions of certain substances, thus their inclusion in the national PRTR system may be considered important. For example in countries with intensive agricultural practices involving large scale application of agrochemical inputs, or in regions where there are many small-scale industrial enterprises, these sources represent an important part of total industrial emissions. In such cases, accounting for the contribution of these non-point or diffuse sources of pollutants in the national emissions inventory is necessary to obtain an accurate portrayal of total emissions. The pollutant contribution of non-point or diffuse sources and their potential health and environmental impacts may also be of importance on a local or regional level. For example in cities where numerous small-scale industrial operations are located throughout the urban landscape, or where vehicular emissions are the largest cause of air pollution, an inventory of non-point emissions from these sources may provide valuable data for local impact/mitigation studies and policy applications.

3. How to Approach the Estimation of Emissions from Non-point or Diffuse Sources?

Estimating the emissions from non-point or diffuse sources requires a different approach and different types of data than those which are needed for point sources of pollutants. Sources of information for estimating the contribution from non-point sources include statistical data on economic activities, demographic data, remote sensing data, emission factors and engineering data. Tools which can facilitate the estimation of emissions from non-point sources include geographical information systems (GIS) and computer models (e.g. hydrology/water flow models, transportation models, etc.).

The general approach for estimating the contribution of non-point sources is to construct appropriate emission factors which are linked to source parameters that are known or easily obtained. These source parameters could be, for example, the number of employees or average output in the case of scattered small- and medium-sized enterprises, the average number of vehicle miles traveled in the case of vehicular traffic, the size and composition of cultivated area in the case of agriculture, the tonnage of pesticide or fertilizer use and the locations where these chemicals are applied, etc. In this manner a reasonable estimate of aggregate emissions arising from non-point or diffuse sources of certain pollutants can be constructed starting from simple parameters that are readily measured or obtained for each source type.

The manner in which non-point source emissions are included in the PRTR, the types of sources which can be feasibly estimated and the level of accuracy to be achieved will be largely determined by the types and quality of available information. Because the availability of information needed for estimating non-point source emissions may vary greatly between countries and for different regions within a country, a important first step in considering what types of non-point sources might be included in the national PRTR system is to evaluate the availability and accuracy of information for each type of non-point or diffuse source. The type of data which is available always constitutes a practical constraint in generating an accurate non-point emissions estimate. However in many cases a quick field test can be performed to measure and calibrate source parameters in order to strengthen an initial estimate.

PART B: Estimating Emissions from Non-point and Diffuse Sources

1. DOMESTIC ACTIVITIES AND USE OF CONSUMER PRODUCTS

1.1 Overview

What are the major source types?

The following emission sources arising from domestic activities and use of consumer products can be distinguished:

- combustion emissions from space heating and cooking;
- emissions of volatile organic compounds from solvents and other solvent containing products;
- emissions to water from cleaning and sanitary processes;
- miscellaneous emissions that can be related to population density, e.g. emissions from corrosion processes, domestic animals, etc.; and
- generation of solid waste.

What are the major pollutants involved and their health and environmental effects?

Indoor space heating and cooking, depending on the technology, might involve emissions of respirable particulates, carbon monoxide (CO), and Benzo[a]pyrene (PAH) which may exceed ambient and guideline levels by several orders of magnitude, particularly when wood is used as fuel. Indoor exposure to these pollutants may cause decreased lung function and chronic respiratory disease.

The use of solvents and other solvent containing products involves releases of volatile organic compounds (VOCs) some of which are known to have carcinogenic and mutagenic effects. These effects might be compounded by the fact that indoor air can be more seriously polluted than outdoor air even in cities of poor air quality.

Emissions to water from cleaning and sanitary processes, emissions (including leachates) from solid waste, and the other miscellaneous emissions mentioned above mainly cause environmental problems through contamination of surface and underground water bodies. The pollutants involved may range from organic waste to synthetic organics and heavy metals, depending on the cleaning process or the nature of the solid waste leachate.

Why are domestic activities and consumer product use treated as non-point sources?

Emissions from domestic activities and product use can be important sources of pollution, especially on a local level. However, the individual sources of these emissions are either too small and/or too numerous to be identified and measured as separate point sources within the inventory. Thus, the emissions from domestic activities and product use, which typically arise from a collection of individual activities within a given area, are generally treated as a diffuse source in an emissions inventory.

What is the relevance of these sources in the context of a national PRTR ?

Depending on its particular situation, a country might consider accounting for emissions associated with domestic activities and product use in its national PRTR system using the approaches described in this section. For nationwide emission inventories, significant contributions to total air emissions of volatile organic substances (VOCs) may arise from domestic and consumer activities and sources related to product use. Phosphates and organics from consumer product use, as well as from solid waste, may also contribute significantly to water pollution. Solid waste itself and leachate emissions from landfills, which represent major environmental management challenges for many countries, could also be accounted for through the PRTR. In the context of a national PRTR system for example, a solid waste module could draw upon information available from a solid waste inventory which the country may already have in place for planning purposes.

Emissions from domestic activities and product use may also be relevant for policy applications or studies that specifically target the local level. For example, indoor air quality is found to be mainly determined by emissions from heating and solvent use. Therefore the types of emission factors that need to be calculated to estimate the emission contribution of diffuse domestic and consumer product use sources can be used both for national and local level applications.

1.2 Estimating Emissions from Domestic Activities and Consumer Products

1.2.1 Data needs

To estimate emissions from domestic activities and consumer product use, two types of data are needed: **emission factors** relating the quantity of emissions to the number of inhabitants, and the **population density** in the area being considered. The common characteristic for domestic activity and product use sources is that pollutant emissions (kg of pollutant released) can be directly related to population density (number of inhabitants per unit area) through the use of per capita emission factors (kg of pollutant released per inhabitant) and marketing statistics (e.g. sales and product use data). Commercial activities, local traffic and some categories of small enterprises are additional examples of sources for which emission output can be related to population density (see also Sections 2 and 4).

In most countries, information is usually available on the number of inhabitants and their geographical distribution. From this information the population density (number of inhabitants / unit area) can be obtained for a defined area within the inventory region.

In some cases emission factors that link emissions from domestic and consumer product use activities to the population density can be calculated from nationwide statistical information. For example, the calculation of a combustion emission factor relating emissions to residential energy consumption involves desegregating nationwide or regional residential energy consumption statistics and allocating them according to population density. The emissions associated with this residential energy consumption can then be derived with the help of fuel related emission factors available from the literature which are specific to the type of fuel used.

Emission factors for emissions associated with the use of solvent containing products are determined by the composition of the products. In some countries regulations require manufacturers or importers to provide this type of information. Countries where this information is not available may be able to use emission factors from other countries with comparable situations, or may derive suitable emission factors by adjusting those which are available. Otherwise, default estimations based on expert judgement should be made. These emission factors are then combined with statistics on the use of solvent containing products according to population density in order to arrive at an estimate of emissions.

In the case of emissions arising from solid waste, statistics about solid waste production and estimates of the composition of the waste in question are required to calculate appropriate emission factors. Where no data is available, undertaking local activity surveys might be a feasible approach to derive an appropriate emission factor. For example, local data for a given consumer product use activity may be available from local sources such as local trade groups, distribution companies or government agencies. A household or commercial survey by questionnaire could also be carried out to obtain the basic data needed to calculate an emission estimate.

1.2.2 Estimation methods

The estimation of emissions for all the consumer and product use related sources mentioned follow similar principles. The emissions can be estimated by multiplying the appropriate "per inhabitant" emission factor by the population density and the area being considered as follows:

emission factor (kg emissions/ inhabitant)	**x**	**population density** (inhabitants/ unit area)	**x**	**area of diffuse source** (total area)	**=**	**emission estimate** (kg emissions)

The emission factor used above is specific to the particular type of source being estimated and the particular pollutant being considered for each of these sources. If a finer geographical resolution of estimated emissions is desired, the total area being considered as a diffuse source should be broken down into smaller areas in which the population density is approximately uniform, and separate estimates should then be generated for each of these smaller areas.

An alternative method for calculating emission estimates for domestic sources and sources related to product use is to use an emission factor directly related to unit area instead of a "per inhabitant" emission factor. The calculation in this case is as follows:

emission factor per unit area (kg emissions/unit area)	**x**	**area of diffuse source** (total area)	**=**	**emission estimate** (Kg emissions)

The examples provided at the end of this section (Examples 1A, 1B and 1C) illustrate the calculation of emission factors as well as how these are combined with population density statistics to estimate emissions from domestic activities and consumer product use.

1.2.3 Level of accuracy and resource requirements

For space heating and cooking the accuracy of these methods depends on the accuracy of the emission factors and how well these emission factors represent the actual mix of domestic combustion devices which are being used in the area under consideration. The accuracy of domestic fuel consumption data is also important. In many cases information is not available on the penetration of different fuel types and domestic devices, therefore average estimates need to be constructed.

In the case of activities related to cleaning, solvent and product use, the accuracy depends on the quality of the consumption or product use data, as well as the quality of the data on the composition of the products which are causing the emissions (e.g. solvents, cleaning agents, etc.). For solid waste, the accuracy of the estimates is also highly dependent on the reliability of the data on the composition of the solid waste as well as the emissions factors which are used.

For all these techniques the time and skill required for data collection is considerable and much depends on the quality of the statistics and/or marketing information available. The identification of representative emission factors requires skilled judgement and/or the use of field tests or surveys to calibrate, validate and/or adjust of international emission factors that are available from the literature. Once appropriate data has been gathered, however, the calculation of the emission estimates is straightforward.

1.2.4 General applications and uses of the estimates

The initial emission estimates for domestic activities and consumer product use provide an indication of the contribution of these sources to total national emissions for inventory purposes. A more detailed analysis of these sources and a refinement of the emission estimates may be of interest for local level public and environmental health studies investigating indoor air pollution, for example, or residential discharges of water pollutants. Emission estimates of this type can also be combined with pollutant diffusion modeling applications enabled through computer models which can be used for even more specific studies. An example of this type might be an investigation into how the pollutant plume from solid waste landfill leachate might be contaminating a groundwater reservoir or acquifer.

<u>Example 1A</u>: Emissions of VOCs from solvent use in City X

Scenario:

City X's environmental authorities are seeking an estimate of volatile organic compounds (VOC) emissions contributed by domestic solvent use. Since population density data is available from a recent census, the authorities decide to calculate an emission factor per inhabitant for domestic VOC emissions from solvent use as a basis for undertaking the estimation.

The following data is also available from the census: City X's urban core has a population density of 300 inhabitants per km^2 and an extension of 15 km^2. City X's urban periphery has a population density of 175 inhabitants per km^2 and covers an area of 50 km^2.

Sample emissions estimation:

The first step is to calculate a suitable per capita VOC emission factor for domestic solvent use using nation-wide information. This will enable authorities to use the available population density data to produce an emission estimate. To obtain data for calculating the emission factor a local survey is conducted. The results of the survey show that the average annual domestic use of cleaning solvents in City X is on average 100 kg yearly per household. The average household size from the City X census data is 4 persons per household. The compositional data for the VOC contained in these commercial cleaning solvents was also determined to be on average 80% of product content by weight. It is assumed that all VOC contained in the solvent evaporates as emissions.

From the above data a per capita VOC emission factor from domestic solvent used can be calculated as follows:

First convert the solvent use data to per capita basis:

100 kg yearly solvent used/household *x* 1 household/4 persons = 25 kg average yearly solvent use/per person

Using the solvent compositional data we can now obtain a per capita emission factor for yearly VOC emissions arising from domestic solvent use:

25 kg solvent used/person *x* 80% kg VOC emissions/kg solvent used = 20 kg VOC emissions/per person/year

continued...

Example 1A, ***continued***

Sample emissions estimation, continued:

With this calculated emission factor and the given population density data, we can use the formula provided in the text to obtain an emission estimate for City X as follows:

For City X's core: 20 kg VOC/person-year *x* 300 inhabitants/km^2 x 15 km^2 = 90,000 kg VOC emissions or approximately 90 tonnes per year

For City X's periphery: 20 kg VOC/inhabitant-year **x** 175 inhabitants/ km^2 x 50 km^2 = 175,000 kg VOC emissions or approximately 175 tonnes per year

Estimation result:

In total for City X we obtain: 90 + 175 = 265 tonnes per year of VOC emissions contributed by domestic solvent use

Example 1B: Nationwide emissions from consumer product use

A top-down estimate of VOC emissions from product use by consumers could also be calculated on a national scale. Information about the use of solvent-containing products like cosmetics, paints and coatings for in-house use, and other consumer products, can usually be obtained from marketing data. Combining this product use information with product composition information obtained from the literature, it is possible to estimate the overall amount of solvents (VOC) evaporating from the household use of these products in the geographic area being considered. The overall VOC emission estimate can then be divided into the number of inhabitants in the area in order to obtain an approximation of the per capita contribution of VOC emissions from consumer product use.

Example 1C: Emissions from space heating in City Y

Scenario:

Environmental authorities for City Y are interested in estimating the NOx emission contribution of domestic heating systems. In city Y these heating systems are limited to two types: fuel oil and natural gas. It is decided that a per capita emission factor for NOx will need to be calculated in order to take advantage of available population density data in undertaking the desired estimation.

In order to gather data for calculating a suitable NOx emission factor, a local survey is conducted to determine average yearly fuel consumption for space heating. It is found that annual consumption of natural gas is 0.1 tonne per capita, and that annual consumption of fuel oil is 200 kg per capita. In addition, data for the amount of NOx released during combustion of each of these fuels is obtained, i.e. 0.2 tonne NOx/tonne of natural gas burned, and 3 kg NOx/tonne of fuel oil burned.

Census data for City Y shows a uniform population density of 200 inhabitants/km^2 and an extension of 70 km^2, with natural gas users clustered around the newer suburbs (20 km^2) and fuel oil users spanning the rest of the urban area (50 km^2).

Sample emission estimation:

Using the above data, a per capita NOx emission factor can be calculated for each fuel type as follows:

The fuel comsumption data is multiplied by the factor giving the weight of NOx released per unit of fuel consumed to obtain a per capita NOx emission factor:

For natural gas: 0.1 tonne/person-year *x* 2 kg NOx/tonne used = 0.2 kg NOx/person-year

For fuel oil: 0.2 tonne/person-year *x* 3 kg NOx/tonne used = 0.6 kg NOx/person-year

With these calculated emission factors and the given population density data we can estimate the annual NOx emissions arising from space heating in City Y as follows:

For natural gas users: 0.2 kg Nox/person-year *x* 200 inhabitants/km^2 *x* 20 km^2 = 800 kg NOx emissions per year

For fuel oil users: 0.6 kg NOx/person-year x 200 inhabitants/km^2 x 50 km^2 = 6,000 kg NOx emissions per year

Estimation result:

In total we obtain for City Y 800 + 6,000 = 6,800 kg per year or approximately 6.8 tonnes of NOx emissions contributed by domestic heating combustion in City Y. To test its accuracy, the estimate can be compared with overall national figures in order to check if the estimated emission contribution of City Y as compared to total national emissions is in line with the city's relative size and importance within the country.

2. TRANSPORT AND TRAFFIC

2.1 Overview

What are the major source types?

The following categories of non-point emissions from transportation sources can be distinguished:

- road traffic (e.g. exhaust emissions, defrosting roads, solid waste, corrosion);
- shipping (e.g. exhaust emissions, water pollution, corrosion);
- railroads (e.g. fuel combustion, corrosion of electrical wires); and
- air transport (e.g. emissions to air, noise).

What are the major pollutants involved and their health and environmental effects?

Transport and traffic related non-point sources cause important contributions to total air emissions of major air pollutant categories (VOCs, NOx, CO, SO_2, PM_{10}), and in particular nitrogen oxides and hydrocarbons. Transport activities and traffic are also sources of air toxics like benzene, 1,3-butadiene, formaldehyde and acetaldehyde. Heavy metals such as Pb, Cr, Cd, Cu and other metallic compounds present in fuel or lubricant additives are also emitted. In addition to air pollution, these sources can also contribute to water and soil pollution if the penetration of modern catalysts is low and significant emissions of lead are released by vehicle fleets. Corrosion and wear may also release heavy metals into the environment.

The health effects of the air pollutants listed above vary according to the intensity and duration of exposure and the health status of the population exposed. Among the documented effects of SO_2, particulates and NOx are increased mortality and deficits in pulmonary function. CO is linked to cardiovascular and neurobehavioural effects. Hydrocarbons of heavy molecular weight such as benzene have been shown to have carcinogenic and mutagenic effects. Exposure to airborne Pb may cause subtle neurobehavioural effects, especially in children.

In terms of environmental effects, NOx and SO_2 form acidic precipitation which affects plants and hence crop yields. These pollutants also contribute to corrosion and damage to various structures and materials. The deposition of many air pollutants, particularly synthetic organics and trace metals, also plays an important role in the pollution of the marine environment. It is now widely acknowledged that CO_2 and O_3 are "greenhouse gases" that contribute to the increase of average global temperature.

Why are transport activities and traffic treated as non-point sources?

The emissions arising from transportation and traffic are generally treated as diffuse sources caused by a collection of individual transportation vehicles that circulate within a defined area. The sheer number of these vehicular sources and their mobility make it impractical to measure or estimate their emissions on an individual basis.

What is the relevance of these sources in the context of a national PRTR ?

Transport and traffic related non-point sources may comprise a significant portion of total air emissions for major air pollutant categories (VOCs, NOx, CO, SO_2, PM_{10}). Air pollutant emissions from transport activities and traffic may in some cases represent the main source of air pollution, particularly at the local level in urban areas. Thus, particularly if the PRTR is intended to provide a comprehensive inventory of air emissions, including in large cities, countries should consider accounting for transport and traffic related non-point sources in their national PRTR systems using the approaches described in this section.

Aside from exhaust and evaporative fuel losses which can be conveniently accounted for in a PRTR, the solid waste produced by cars might present a problem in its own right that has yet to be adequately solved in many countries. However, accounting for solid waste is outside the scope of most PRTR systems, which in general are focused on releases and transfers of chemical substances. Vehicle solid waste can be taken into account outside the context of a PRTR system through specific solid waste inventories.

What are the potential challenges and resource requirements?

The estimation of emissions from transport and traffic sources can demand considerable time and skill. This applies in particular to the collection of activity data which reliably reflects the local use of different transport vehicle categories. Likewise the adjustment of internationally available emission factors to local conditions of use, climate, and equipment, or the calculation of indigenous ones, can also be technically demanding. Once reliable data is available, however, the actual estimation of emissions requires little expenditure of resources.

What are the general applications and uses of these estimates?

The emission estimates from transport and traffic activities give the contribution of these sources to total air emissions in the country. In most practical cases this contribution will be important and these sources need to be included in the inventory in order to obtain a complete picture of national emissions. Emission estimates for specific transport and traffic source categories may also be undertaken in the context of more specific local level studies, for example developing an air pollution control programme for a large city to target buses or passenger car fleets. Another example would be a study focusing on air quality in the vicinity of an airport or port to derive appropriate emission mitigation measures from airplanes or shipping activities.

2.2 Road Traffic

Road traffic emissions are caused by passenger vehicles, trucks and motorcycles which generally use fuels such as petrol (leaded and unleaded), diesel and liquefied petroleum gas (LPG).

2.2.1 Data needs

Two types of data are needed to estimate the emissions from road vehicles. The first type consists of **emission rates on a mass per vehicle kilometer traveled (VKT) basis**. The unit emission rate gives the quantity (kg) of pollutant emitted per each kilometer traveled by a vehicle of a particular class. The second type of data consists of **statistics on distance traveled for each vehicle type and travel mode**, as explained below.

Regarding the first type of data, a unit emission rate on VKT basis needs to be calculated for each class of vehicle being considered in the estimation. The vehicle fleet in the area being considered will typically comprise several classes of vehicles. The mean emission rate for an average traveling vehicle of each class should be calculated using available data. The data needed for the calculation of these emission rates includes:

- the distribution and amount of fuel use over the different vehicle types (petrol, diesel, LPG);
- engine combustion characteristics for each vehicle class;
- the age and size of the vehicles; and
- the extent of catalyst use.

As these factors are continuously developing, the emission rate for each vehicle class should be continuously updated, in most cases at least yearly.

Beyond emission rates on a VKT basis, the second type of data needed for the estimation of emissions arising from road traffic consists of statistics on distance traveled by vehicle type and travel mode. The travel mode categories include highway traffic, town traffic, and traffic on other roads. Statistics for each of these travel modes and for each type of vehicle (i.e. passenger cars, trucks, and motorcycles) need to be obtained to undertake the VKT-based emission estimation. These statistics might be available from transport planning and traffic authorities, although this is not always the case.

From these travel mode statistics for each vehicle type the traffic production can be obtained. The traffic production is the aggregate Vehicle Kilometers Traveled (VKT) in the area being considered. For example, the traffic production for individual roads can be determined by counting the number of cars passing by and multiplying it by the length of the road belonging to the measured intensity assuming all cars travel the full length.

It must be borne in mind that the VKT data need to be further resolved according to travel mode (i.e. highway, town traffic and traffic on other roads), vehicle type (passenger vehicles, commercial vehicles, heavy duty vehicles and motorcycles), fuel use (petrol, diesel and LPG) and vehicle age (i.e. pre-1976, 1976-1985 and post-1985 vintages). This resolution is needed since a different emission rate applies for each combination of travel mode, vehicle type and age, and fuel use.

2.2.2 Estimation methods

Emission rates on a VKT basis have to be calculated for each travel mode/vehicle type/fuel use combination, yielding an emission rate on a VKT basis for each combination category. The product of these unit emission rates times the total vehicle-kilometers traveled in each category is equal to the total vehicle exhaust emissions, as follows:

emission rate on VKT basis (kg emissions/ vehicle-km-traveled)	**x**	**total vehicle-kilometers traveled** (vehicle-km-traveled)	**=**	**emissions per travel mode/ vehicle type/fuel use category** (kg of air emissions per category)

To obtain total air emissions from road traffic in the area under consideration, the above emission estimates need to be aggregated across all categories (travel mode/vehicle type/fuel use) present in the area in question. The sum would give an estimate of the contribution to air emissions from road traffic. An illustration of this estimation method is provided in Example 2A.

An alternative approach to arrive at rough nationwide traffic production estimations involves the use of information about national fuel consumption, such as gasoline sales (see Examples 2B and 2C). The aggregate fuel consumption figure for road vehicles can be very roughly translated into an approximate emission estimate in combination with knowledge about the composition of the vehicle fleets, travel patterns, etc. by expert judgement. It should be kept in mind that such estimates may be of limited use when local level accuracy is desired.

2.2.3 Level of accuracy and resource requirements

The VKT method is comprehensive and detailed but its accuracy and reliability depend on the quality of the data used and the validity of assumptions made. Considerable time and skill is required to estimate motor vehicle emissions based on the technique presented. Typically it can require several months of professional time for large cities. An alternative approach is to use internationally available emission rates and apply local VKT data to them. Such an approach can reduce significantly the time needed to generate an inventory of motor vehicle emissions, but still requires that accurate data be present for Vehicle Kilometers Traveled for each travel mode/vehicle type/fuel use category of importance in the country. The use of foreign emission rates will also decrease the accuracy of the estimation if adjustments for differences in fleet composition, fuel characteristics and climatic factors are not made.

2.2.4 Additional applications and analyses

Aside from exhaust emissions, road vehicles are also a source of evaporative emissions, which account for a significant proportion of total motor vehicle emissions of HC according to recent studies. Certain air toxics such as benzene, 1,3-butadiene, formaldehyde and acetaldehyde can also be present either in exhaust or evaporative loss emissions from motor vehicles. Speciation profiles can be used to obtain disaggregated estimates for these emissions. A detailed presentation of the estimation of these emissions is beyond the scope of this document, but several studies exist that can be used to estimate toxic emissions as fractions of total organic gases present in exhaust or the evaporative losses of road vehicles.[2] Estimation of evaporative losses from motor vehicles represent an additional level of analysis that countries might wish to undertake.

Another type of activity related to road traffic that could be analyzed are seasonal defrosting activities, as well as wear and corrosion. Defrosting can cause emissions to water and soil which can be derived from information on the amount of salt or other substances used in a given season. Some countries have analyzed the contribution of the road vehicle sector to solid waste production. However such analyses are generally not undertaken in the context of a PRTR system, as they relate more to information about vehicle scrapping or recycling methods.

[2] National Pollutant Inventory. Emission Estimation Techniques Report. Dames & Moore 1996 for the Environmental Protection Agency of Australia. Vol. 1, Appendix D, pp.3-7.

Example 2A: Air emissions from a single road

Scenario:

Local authorities are interested in estimating the yearly NOx and VOC emissions contributed by road traffic in a single stretch of road measuring 100 km. The following data is available for this road:

- the road is used by only two types of vehicles (agricultural trucks and cars);
- available VKT-based emission factors for agricultural trucks are given as .00223 kg SO2/VKT and .00314 kg NOx/VKT for the two pollutant categories of concern;
- VKT-based emission factors for cars are given as .00105 kg SO2/VKT and .00231 kg NOx/VKT;
- the road is used by 300 trucks and 150 cars every day of the year.

Sample emission estimation:

With the above road use information, the vehicle-km-traveled (VKT) during the year can be calculated for this road as follows:

Annual VKT for agricultural trucks:
300 trucks/day x 365 days/year x 100 km = 10.95 million VKT

Annual VKT for cars:
150 cars/day x 365 days/year x 100 km = 5.48 million VKT

Once the respective VKT is calculated for each vehicle type, we can proceed to estimate emissions using the formula given in the text.

Emissions contributed by agricultural trucks:

.00223 kg SO_2/VKT x 10.95 million VKT = 24,419 kg SO_2 per year
.00314 kg NOx/VKT x 10.95 million VKT = 34,383 kg NOx per year

Emissions contributed by cars:

.00105 kg SO_2/VKT x 5.48 million VKT = 5,754 kg SO_2 per year
.00231 kg NOx/VKT x 5.48 million VKT = 12,659 kg NOx per year

Estimation result:

The total contribution of traffic activity on this road is therefore approximately:

Example 2B: Emissions from a small town in which annual fuel use and vehicle fleet composition data are available

Scenario:

Authorities in Town X are interested in estimating the annual traffic-related emissions of several air pollutant categories (NOx, SO_2, VOC, and Pb). The following statistics are available for the town:

- 1200 tonnes of unleaded fuel are used yearly by municipal buses and 1000 tonnes of leaded gasoline are used yearly by passenger cars within the urban area;
- The vehicle fleet composition is fairly uniform and limited to municipal buses and passenger cars of recent make.
- Emission factors for the two vehicle engine types and fuel given are available from the literature. For municipal buses the emission factors are: 24 kg VOC/tonne of fuel; 27 kg NOx/tonne of fuel; 20 kg SO_2/ tonne of fuel; and 0.0 kg Pb/tonne of fuel (unleaded). For passenger cars the emission factors are: 27 kg VOC/tonne of fuel; 22 kg NOx/tonne of fuel; 20 kg SO_2/tonne of fuel; and 1.35 kg Pb/tonne of fuel.

Sample estimation of emissions:

With the given data we can estimate emissions of each air pollutant category contributed by each vehicle type as follows:

Emission contribution of municipal buses:

24 kg VOC/tonne of fuel x 1200 tonnes = 28.8 tonnes of VOC
27 kg NOx/tonne of fuel x 1200 tonnes = 32.4 tonnes of NOx
20 kg SO_2/tonne of fuel x 1200 tonnes = 24.0 tonnes of SO_2
0.0 kg Pb/tonne of fuel x 1200 tonnes = 0.0 tonnes of Pb

Emission contribution of passenger cars:

27 kg VOC/tonne of fuel x 1000 tonnes = 27.0 tonnes of VOC
22 kg NOx/tonne of fuel x 1000 tonnes = 22.0 tonnes of NOx
20 kg SO_2/tonne of fuel x 1000 tonnes = 20.0 tonnes of SO_2
1.35 kg Pb/tonne of fuel x 1000 tonnes = 1.35 tonnes of Pb

Estimation result:

We aggregate the emission contribution across vehicle types to yield a total yearly estimate for the emission contribution from traffic in the small town for each air pollutant type:

28.8 + 27.0 = 55.0 tonnes of VOC
32.4 + 22.0 = 54.4 tonnes of NOx

Example 2C: Nationwide emissions from transport and traffic

The estimation approach for the small town described in the previous example is usually not practicable because the amount of fuel used in a single town by general traffic is rarely available. The approach is generally practicable only for city buses or other specific vehicle types for which authorities might have fuel use information for a particular town.

The total amount of fuel used, however, is usually available on a national scale, where statistics are often available for aggregate fuel use by each fuel type. Starting from these overall national fuel use figures, several estimation approaches are possible depending on what additional information is available. The additional information consists of the distribution or breakdown of the overall fuel use into the different driving modes.

If the distribution of overall fuel use over the different driving modes is not available, then a mean emission factor can be used to obtain an estimate of total national emissions contributed by transport and traffic by multiplying the national fuel use figures by the mean emission factor. The estimate of total emissions can then be divided into the number or inhabitants in order to calculate an average emissions per inhabitant from transport and traffic sources. The average emissions per inhabitant can then be used to obtain an approximation of traffic emissions for the town based on the number of inhabitants.

If the distribution of fuel use over the different driving modes is available, then emission factors for these driving modes can be used to obtain a better approximation of total national emissions from transport and traffic. From this number the average emissions per inhabitant can be estimated, and these are then applied to estimate the traffic emissions of particular towns. It is important to note that this “top-down” approach for emission estimation only works if the contribution of international traffic is small in relation to inland traffic, or if the fuel used by ingoing and outgoing traffic is approximately equivalent. In the case of road traffic this approach generally results in a good approximation but in small countries the assumption might not apply to shipping or aircraft emissions.

2.3 Shipping

Marine craft are an extremely diverse category ranging from small outboards to large international cargo ships. The chemical species emitted by this sector include the major categories of air pollutants: VOCs, NOx, CO, SO_2, PM_{10}; the same air toxics mentioned for road motor vehicles: benzene, 1,3-butadiene, formaldehyde and acetaldehyde; and heavy metals such as Pb, Cr, Cd, Cu, and other metallic compounds present in fuel or lubricant additives. Shipping activity may also contribute to water pollution through accidental spills, routine leakage of lubricants and/or as a result of ship cleaning and maintenance activities.

In most cases a detailed inventory of emissions due to shipping will only be required for local or regional studies for environmental or health applications, for example in the vicinity of ports or inland shipping routes where shipping activities may be causing health and environmental impacts.

2.3.1 Data needs

To estimate air emissions from marine craft, two types of information are needed: **emission factor data**, and **activity data**. Emission factors per engine type or per class of marine vessel need to be obtained. These emission factors reflect the quantity (in kg) of pollutants emitted per liter of fuel consumed or per horsepower-hour of engine use. Commercial marine vessels are divided into three classes by the U.S. Environmental Protection Agency (USEPA, 1992), i.e. ocean going, harbor and fishing vessels. The classes have similar characteristics of size, speed, engine design and distance traveled so aggregation is possible to a certain extent when calculating emission factors applicable to each class. The USEPA has published emission factors for commercial vessels in a number of reports (USEPA 1985, 1991c)[3]. The Lloyds Company also determines emission factors per unit of fuel under circumstances met in practice for seagoing shipping.

Activity data refer to statistics on hours of activity or fuel consumption which might be available from port authorities, ferry companies, and fishing regulatory bodies. For the purpose of an emission inventory the relevant emissions will occur in the vicinity of the port. Port authorities are usually able to provide information on the number and types of ships which are docked and the period of time spent docked, approaching or leaving the port, as well as the quantities of freight being transferred. Lloyds Register is also an excellent source of information on the intensity of shipping traffic and its location, including inland routes of seagoing ships which can be combined with local information from harbor authorities for a detailed analysis of emissions due to the seagoing shipping mode.

The above information can be used as primary activity data for the estimation of emissions contributed by shipping activities in the vicinity of the port. It must be borne in mind in relation to fuel consumption data that the majority of the fuel will be consumed at sea,

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[3] USEPA 1985, "Compilation of Air Pollutant Emission Factors, Vol. I, Stationary Point and Area Sources", 4th Ed. Research Triangle Park, NC, USA. USEPA 1991(c),"Nonroad Engine and Vehicle Emission Study-Report", EPA 460/3-91-02, Ann Arbor, MI, USA.

therefore local port fuel sales will not accurately reflect emissions occurring in the airshed in the vicinity of the port. Activity data is therefore preferred for estimating emissions in the inventory region unless fuel consumption data is adjusted accordingly.

The emission factors and activity data discussed above allow the estimation of emissions for the major air pollutant categories. If for the purposes of the inventory more detailed estimates of certain air toxics or particulates are required, speciation profiles for the VOCs and particulates emitted for each category of marine vessels will also be needed to desegregate the original estimates.

2.3.2 Estimation methods

The principles for the estimation are similar to those presented for road vehicles in that an appropriate emission factor for each marine vessel category is multiplied by a variable indicating the activity or fuel use for that vessel category in the inventory region, as follows:

emission factor for each vessel category (kg emissions/ horsepower-hour)	**x**	**activity variable in area being considered** (total horsepower-hours)	**=**	**emissions per vessel category** (kg of air emissions per vessel category)

An alternative approach, illustrated in Example 2D, is to calculate an emission factor directly related to fuel consumption, using the following equation:

emission factor for each vessel category (kg emissions/unit fuel consumed)	**x**	**fuel consumed within area being considered** (total fuel used)	**=**	**emissions per vessel category** (kg of air emissions per vessel category)

This approach gives an emission estimate for each vessel category for the major types of air pollutants. If the air pollutant estimates need to be further speciated, that is, broken down into their constituent chemical species, the speciation profile for VOC and particulates for different vessel categories can be used to break down these first estimates into a series of emission estimates for each relevant species. Once the appropriate estimates are calculated for each marine vessel category within the area being considered, the estimates can be aggregated to obtain an overall estimate for the emission contribution due to shipping activities.

An estimate of emissions from inland shipping can be based on the amount of fuel used and the traffic production of certain shipping routes. In this case it can be assumed that the majority of the fuel consumed is turned into emissions in the inventory region that the inland shipping route crosses. Traffic production data (number of vessel-kilometer-traveled) for each vessel category in the shipping route can also be used in a similar approach as the one presented for road vehicles. Water pollution due to oil losses in inland shipping routes can

Example 2D: Emissions for one vessel category for which fuel consumption data is available

Scenario:

Authorities in Port X are interested in estimating the yearly air emissions contributed by the main vessel category, in this case fishing trawlers. The following data are available:

- Yearly fuel consumption data for this vessel category in the vicinity of the port is estimated to be 15,000 tonnes of fuel oil;
- Most fishing trawlers at Port X are of the same size and type of engine;
- Emission factors per unit of fuel consumed for the engine type common to this vessel category are available from the literature for the major air pollutant types. These emission factors are: 35 kg VOC/tonne of fuel; 27 kg NOx/tonne of fuel; 23 kg SO_2/tonne of fuel; and 3.0 kg Pb/tonne of fuel consumed.

Sample emission estimation and result:

Using the data given we can directly apply the formula in the text to estimate the yearly air pollutant emissions contributed by the fishing trawler category in the vicinity of the port. The estimation consists of multiplying the emission factor times the amount of fuel consumed, as follows:

35 kg VOC/tonne of fuel x 15,000 tonnes = 525 tonnes of VOC
27 kg NOx/tonne of fuel x 15,000 tonnes = 405 tonnes of NOx
23 kg SO_2/tonne of fuel x 15,000 tonnes = 345 tonnes of SO_2
3.0 kg Pb/tonne of fuel x 15,000 tonnes = 45 tonnes of Pb

also be estimated based on the number and vessel categories present on the routes.

2.3.3 Level of accuracy and resource requirements

The overall accuracy of the technique described is low due to the numerous uncertainties in the emission factors, activity data, and in the speciation profiles used to estimate toxic emissions. The amount of time needed to collect reliable activity data also can be considerable. An appropriate distinction should be made between seagoing, inland, and recreational shipping. For example, in areas where recreational shipping is the predominant activity the estimation is complicated by the fact that the activity is very much determined by seasonal variations. Therefore the estimations of actual activity and fuel use data require a lot of expert judgement and are difficult to obtain.

2.4 Railroads

Railway locomotives are a diverse category although not as varied as shipping vessels. The emissions from this sector include the major categories of air pollutants (VOCs, NOx, CO, SO_2, PM_{10}), the same air toxics mentioned for road vehicles and shipping (benzene, 1,3-butadiene, formaldehyde and acetaldehyde), and heavy metals such as Pb, Cr, Cd, Cu, and other metallic compounds present in fuel or lubricant additives.

2.4.1 Data needs

Estimating the emissions to air from railway locomotives requires two types of data: **emission factors by engine type** for the local locomotive fleet, and **fuel consumption by engine throttle position** (or travel mode). Emission factors for railway locomotives available from the USEPA (1992)[4] are divided into three classes based on the scale of railway operations and either line haul or yard use. The same document provides methods to tailor these emission factors to suit a fleet differing from the US average. For this adjustment the composition and engine types of the local fleet are required. In particular, an accurate adjustment will require the composition of the local fleet to be specified in terms of locomotive type, engine type, and mode of service.

Fuel consumption for the inventory area may be available from state rail networks. If not, fuel consumption may have to be estimated based on the relative freight carried through the area being considered. For an accurate estimate, the fuel consumption data should be specified in terms of fuel consumption by engine throttle position, and percentage of time in each position for line haul and yard operations. In many cases this data is available from railway companies.

2.4.2 Estimation methods

The principles for the estimation are similar to those presented for road vehicles. An appropriate emission factor for each locomotive class is multiplied by a variable indicating

[4] USEPA, 1992, "Procedures for Emission Inventory Preparation, Volume IV: Mobile Sources", EPA 450/4-81-026d, Office of Mobile Sources.

the fuel consumed by that class within the geographical area covered by the inventory, as follows:

emission factor for each locomotive class (kg emissions/unit fuel consumed)	x	**fuel consumed in area being considered** (total fuel used)	=	**emissions per locomotive class** (kg of air emissions per locomotive class)

This approach gives an emission estimate for each locomotive category for the major types of air pollutants. If the air pollutant estimates need to be further speciated, that is, broken down into their constituent chemical species, the speciation profile for VOC and particulates for different locomotive classes can be used to breakdown these first estimates into a series of emission estimates for each relevant species. Unfortunately only limited data are available on the emission of toxic chemicals as a fraction of exhaust and evaporative VOC.

Emissions from electrified railroads are limited to copper emissions from wear of overhead wires. The railroad companies usually can derive this information from the wear losses at their replacement programme.

2.4.3 Level of accuracy and resource requirements

The overall accuracy of the technique described is low given the numerous uncertainties in the emission factors and fuel consumption data, and the limited data on speciation profiles used to estimate toxic emissions. In addition, the amount of time needed to collect reliable fuel consumption data by engine throttle position and to adjust international emission factors to reflect the composition of the local locomotive fleet can be considerable.

2.5 Air Transport

The emissions from aviation are considered only in the vicinity of airports. More specifically, exhaust emissions from aircraft are considered for idling, taxiing, taking off, ascent to the mixing layer height, descent from mixing layer height, landing and taxiing to the terminal. The taxi/idle phase is in general the most polluting stage.

The emissions of aircraft include the major categories of air pollutants (VOCs, NOx, CO, SO_2, PM_{10}) and a wider range of air toxics than those mentioned for other transport activities. These air toxics include: 1,3-butadiene, formaldehyde, other aldehydes, acetone, benzene, toluene, benzene, ethyl benzene, xylene, styrene and phenol.

2.5.1 Data needs

Calculation of emissions from air traffic are based on the **number of landings/take_off cycles (LTO)** per aircraft type. Normally airport records indicate aircraft movements in the form of single takeoff or landing, which represent a half landing/take-off cycle. Most aircraft during a full LTO go through a similar sequence of operations characterized by fairly standard power settings for given aircraft categories. Thus from the number of LTOs for each aircraft category, the time spent in each engine power setting mode, or **time in mode (TIM)**, for each aircraft category needs to be determined in the vicinity of the airport. LTOs and TIMs are activity data analogous to the activity data previously described for road vehicles and shipping. The third type of data needed are **emission factors** for specific aircraft engines at each of the power settings that aircraft go through during a take-off/landing cycle (LTO). These emission factors are available from the literature.[5]nonrdmdl.htm),[6]

2.5.2 Estimation methods

Because most aircraft categories (commercial, general, and military aviation) go through a similar sequence of standard power settings during an LTO, emissions can be estimated by multiplying the appropriate emission factor for each power setting by the time spent in each power setting or operating mode (TIM) for each aircraft category in the airport being considered. The steps in estimating aircraft emissions in the vicinity of airports have been identified by USEPA[7] as follows:

1. Identify all airports to be included in the inventory.
2. Determine the mixing height to be applied to the LTO cycle (i.e, the boundary height).
3. Define the fleet make-up for the aircraft category using each airport.
4. Determine airport activity as the number of LTOs for each aircraft category.
5. Select emission factors for each aircraft category.
6. Estimate a time in mode or power setting (TIM) for each aircraft category at each airport, keeping in mind that the taxi/idle mode for the same aircraft category might vary for different airports depending on the airport's size.
7. Calculate the inventory emissions based on the airport activity (LTOs), TIM, and aircraft category emission factors.

After calculating (a) the LTOs for each aircraft category and (b) the TIMs for each aircraft category, the emission estimation can then be carried out. An emission factor specific for each aircraft engine category and operating mode is multiplied by the time spent on that operating mode and the corresponding fuel flow for that engine category. The result of this multiplication is an estimate for the emissions contributed by the aircraft engine category during the time spent in the operating mode being considered. The procedure, which is illustrated in Example 2E, is as follows:

[5] FAA, "FAA Aircraft Engine Emission Database (FAAEED)", U.S. Federal Aviation Administration (FAA) Technology Division, Office of Environment and Energy, Washington, DC, USA. (http://www.epa.gov/omswww)

[6] USEPA 1991(c),"Nonroad Engine and Vehicle Emission Study-Report", EPA 460/3-91-02, Ann Arbor, MI, USA.

[7] Ibid.

Emission factor for taxi/idle mode for each aircraft category	x	**time in taxi/idle mode**	x	**fuel flow**	=	**emissions for taxi/idle mode**
(kg emissions/1000 kg fuel)		(TIM minutes)		(kg fuel/min)		(kg of air emissions)

The same calculation is repeated for each of the three operating modes (TIMs), i.e. taxi/idle mode, takeoff and approach/climbout. Next, the calculated emissions for the three operating modes are aggregated for each aircraft category to arrive at an emission estimate per category. Finally by summing the emissions estimated for each aircraft category the total emissions estimate for the airport being considered is obtained.

2.5.3 Level of accuracy and resource requirements

Individual airports and aviation control bodies generally keep sufficient records to enable the required activity data required (LTOs and TIMs) to be reliable and of high quality. Emission factors based on engine testing are available for most aircraft engines at the required power setting and/or operating modes. These emission factors are also generally of high quality. If care is taken in the analysis of activity data (LTOs and TIMs), the estimation of aircraft emissions through these techniques can be fairly accurate.

It should be noted, however, that the estimation of aircraft emissions involves several analytical steps, and that obtaining and analyzing activity data can be complicated. Sometimes activity data may not be available in a ready-to-use form, or it may vary widely for different airports. For all these reasons, considerable professional time can be spent in undertaking an analysis of this nature.

Example 2E: Estimating emissions for one aircraft category for which LTO and TIM data are provided

Scenario:

Authorities are interested in estimating the aggregate air pollutant emissions from air traffic in the vicinity of Airport X which serves an agricultural town. The following data are available:

- Air traffic activity in Airport X consists of 5000 LTO (landing-takeoff) cycles per year of small mono-motor aircraft.
- The times is each engine operating mode (TIM) for this aircraft category during each LTO cycle are: taxi/idle TIM 8 minutes, takeoff TIM 3 minutes, approach/climbout TIM 10 minutes.
- The emission factors for each engine operating mode (TIM) for this aircraft category as given in the literature are: 360 kg/tonne fuel in taxi/idle mode; 480 kg/tonne fuel in takeoff mode; 230 kg/tonne fuel in approach/climbout mode. These emission factors give the aggregate weight of air pollutant emissions (VOC, NOx, CO, SO2 etc.) per tonne of fuel used. A pollutant speciation profile, which is specific to the fuel used, needs to be used later to break down the aggregated estimate of air pollutant emissions into its constituent estimates for each air pollutant category.
- The fuel flow during each engine operating mode (TIM) for this aircraft category are obtained from the literature as: 0.22 kg/min in taxi/idle mode; 0.65 kg/min in takeoff mode; 0.15 kg/min in approach/climbout mode.

Sample emission estimation:

Using the above data the formula given in the text is directly applied to estimate yearly aggregate air pollutant emissions in the vicinity of the Airport X for the mentioned aircraft category. Care should be taken in correctly aggregating the partial results to arrive at the total emissions estimate. The first step is to apply the formula to estimate emissions for each aircraft engine operating mode (TIM) during a single LTO cycle as follows:

Emissions from taxi/idle operating mode during each LTO cycle:
360 kg/tonne fuel x 8 min x .00022 tonne fuel/min = .63 kg

Emissions from takeoff operating mode during each LTO cycle:
480 kg/tonne fuel x 3 min x .00065 tonne fuel/min = .94 kg

Emissions from approach/climbout operating mode during each LTO cycle:
230 kg/tonne fuel x 10 min x .00015 tonne fuel/min = .35 kg

continued.../

Example 2E, ***continued***

These intermediate results are then summed to obtain an emission estimate for one complete LTO cycle as follows:

.63 + .94 + .35 = 1.92 kg of aggregate air pollutant emissions per each LTO cycle.

Finally, to obtain the estimated yearly air emissions which occur in the vicinity of the airport, we simply multiply this figure by the total number of yearly LTO cycles in Airport X:

1.92 kg air emissions/LTO x 5,000 LTO cycles in the year = 9,600 kg of yearly air emissions

Estimation result:

The resulting estimate is 9,600 kg of aggregate air pollutant emissions per year. An emission speciation profile can then be used to break down this total into its constituent air pollutant categories (i.e VOC, NOx, SO_2, CO, PM etc.)

3. AGRICULTURE

3.1 Overview

What are the major source types?

The following categories of non-point source emissions from agriculture-related activities can be distinguished:

- use of pesticides, herbicides, and fungicides;
- excess manure production;
- burning of waste biomass; and
- combustion emissions from use of tractors, harvesters and other motorized equipment, heating of greenhouses, etc.

What are the major pollutants involved and their health and environmental effects?

Direct pollution from agricultural activities is mainly related to fertilizer and pesticide use. Fertilizer nutrients contribute to eutrophication in surface water, nitrate accumulation in ground water, acidification of soil, and emissions of N_2O (a gas that contributes to the greenhouse effect). Leaching of nitrate to ground water and surface water also threatens drinking water sources in many areas. Nitrogen (N) and phosphate (P) losses to surface waters contribute to eutrophication of lakes, rivers, and shallow seas. The use of waste organics as fertilizer, such as manure and sewage sludge, may also cause accumulation of heavy metals in soils.

Pesticides, herbicides and related agrochemicals (particularly the organochlorine variety) may be transported by wind or water, resulting in hazardous concentrations in the surface water and in soils. Pesticides that do not degrade easily or disappear by volatilization or adsorption may cause long-term health and environmental effects. These pesticides and their metabolites may also migrate to groundwater systems, thereby contaminating present and future drinking water resources. Pesticides also may affect non-target organisms such as pollinating insects and the pests' natural predators and parasites, thereby disturbing natural regulating mechanisms. Another problem is the development of pest resistance to specific pesticides which can lead to a vicious cycle of higher dosages being used to combat ever more resistant pest species.

Very severe local water pollution can often result from the discharge of organic waste (solids, organic matter leading to high oxygen demand, and bacteriological agents) resulting from the processing of agricultural crops or waste from animal farms. The burning of agricultural waste can also contribute to local air pollution. Anaerobic degradation of organic waste (e.g. straw in rice paddy fields, or landfills) releases CH_4 which, together with CO_2, contributes to the global greenhouse effect.

Why are the agriculture-related sources treated as non-point sources?

The emissions arising from agriculture-related activities are treated as non-point sources because they are caused by a collection of individual events which are periodic and too numerous to consider identifying as separate point sources within the inventory, nor can they be measured separately for practical reasons. These events range from the application of agrochemicals and use of motorized equipment in farming operations to the release of excess animal manure.

What is the relevance of these sources in the context of a national PRTR ?

Agriculture related non-point sources may represent important contributions to total national pollutant emissions, particularly in countries where the use of agrochemicals and modern agricultural production techniques is widespread. In areas where agricultural production is intensive, the primary application of agrochemicals such as pesticides, herbicides, and fertilizer can cause significant pollutant loading of catchment waters via runoff containing residues from these applications. Eutrophication is a widespread phenomenon that affects water bodies receiving nitrates and phosphates in this manner. In areas where animal husbandry practices are intensive, these activities usually become important sources of conventional water pollutants such a as solids, biological oxygen demand, nutrients and bacteriological agents.

In most countries the contribution of agriculture to national pollution is mainly caused by pesticide and fertilizer use. The burning of biomass waste and the use of motorized agricultural equipment are often only of local importance. Manure production tends to cause problems only in those countries whose practices are so intensive as to disrupt the natural absorption of this material as soil fertilizer.

What are the potential challenges and resource requirements?

Rough estimates of pollutant emissions from agriculture-related activities can often be obtained from primary production and use data. These includes information on the types and quantities of crops produced, the formulation and volumes of pesticides and fertilizer used, animal counts, etc. For calculation of estimates from primary data the level of skill and time requirements should be moderate. However, because these methods allow only limited geographical resolution of emissions and do not provide a detailed speciation of pollutant categories, they are of limited use beyond the purposes of a very general emissions inventory. For example, for studying the pollutant loading caused by agriculture related-sources in watersheds and catchment waters, which tend to be the main concerns in relation to agricultural sources, a finer level of detail would be required.

If the estimation of diffuse water pollutant emissions is to go beyond rough aggregate estimates to a localization of pollutant flows in watersheds and national water bodies, it will require the use of runoff or diffuse water pollution computer models. The more detailed agriculture-related emission estimation methods are inherent components of runoff and diffuse water pollution models applied by watershed managers or agencies interested in the overall pollutant loading of relevant watersheds or catchment waters. The use of these techniques is both time and skill intensive and will probably have to be undertaken in collaboration with regional water and agricultural authorities who may have the required local level information necessary to run these models.

A further difficulty in the context of estimating emissions to water from agricultural diffuse sources is that it may double count certain atmospheric emissions of pollutants which settle on land surfaces and subsequently contribute to water pollution via runoff. In addition, the emission estimation techniques and models available for these sources tend to concentrate on conventional water pollutants (i.e. solids, biological oxygen demand, nutrients and bacteriological agents) and tend not to specifically address toxic pollutants, which are usually the prime concern of PRTR systems.

What are the general applications and uses of these estimates?

For countries facing challenges of water pollution and eutrophication, undertaking an analysis of agricultural sources of emissions and their impact on national water bodies in the context of a national PRTR system could be a useful step in assessing baselines and developing appropriate sectoral policy responses. Also if an inventory of greenhouse gases is to be included in the national PRTR system, the contribution of greenhouse gases from agricultural activities is likely to be relevant. An inventory of agricultural pollutant emissions can also be an invaluable resource for land use and water planning purposes as well as local level environmental quality studies.

3.2 Pesticide Use

Pesticides are unique as environmental contaminants because they are specifically designed as biocides which are deliberately released to the environment for purposes of pest management and weed control, both in agriculture as well as in the urban environment. Pesticides can be divided into major classes including insecticides, fungicides, herbicides and other minor groups such as acaricides and piscidices. Pesticides may contain synthetic or naturally occurring organics, inorganic compounds, and petroleum solvents used as carriers for the active compound. More than 450 different compounds are found in existing formulations of pesticides.

Pesticides are normally formulated as liquids, aerosols, or as dry powder or pellets. Both the solvent carrier and the active compound usually vaporize and contribute to VOC emissions. However liquid formulations can either be water or solvent based mixtures of the active compound, so that the VOC content of the formulation can vary substantially from product to product. Certain varieties such as DDT and aldrin do not volatize quickly and are more persistent.

3.2.1 Data needs

There is a range of techniques available for estimating pesticide emissions to the environment. The amount of data required for technique varies in accordance with its level of sophistication. For rough estimates based on manufacturing/formulation processes and use data, the basic data set consists of the **volumes of pesticides used**. This information can be estimated from sales data, import data and, where available aerial spraying records and/or license records that reflect volumes of pesticide applications. If the volumes of pesticide used can be further desegregated by location of application, some degree of geographical resolution or apportioning of the estimates by region becomes possible. To further develop these estimates of pesticide volumes used into emissions by environmental compartment (e.g. air, water, soil), **partitioning ratios** applicable under local conditions are required.

Next in terms of accuracy are the estimation techniques based on **pesticide residue data** generated through monitoring programs. These techniques require monitoring data for pesticide residues in air, soil and water, in addition to the basic data set mentioned above. Access to this data depends on the availability and comprehensiveness of local pesticide monitoring studies.

Finally, there are the estimation techniques based on mathematical models. There are several types of computer models available, of which many are proprietary. The types of data required would vary according to the particular model and model type.

3.2.2 Estimation methods

For the estimation of emissions based on the volume of pesticides used, a top_down as well as a bottom_up approach can be used. In the top-down approach, which is illustrated in Example 3A, statistical information about production, sales and the import/export of pesticides is gathered to determine the volume of pesticides used, preferably desegregated by the geographical areas under consideration. From the initial calculation of pesticide sales, the actual amounts being applied should be estimated. This step is complicated by the fact that pesticides sales for a particular year do not necessarily equal pesticide usage in the same period since pesticide application is driven by pest pressure and the given amounts sold may be used during subsequent years.

Once the pesticide volumes used in the areas being considered are calculated, emissions can be estimated for each class of pesticide based on partitioning ratios that give the estimated emissions to air, soil, and water expected from these pesticide applications. However taking the estimation to this level of detail requires that partitioning ratios, which are highly dependent on the particular nature of the environment where the pesticide is being released, are available. Because this data is often not available for local use conditions, the top-down approach will often not yield much detail on individual substances being released to various environmental media. Rather, the focus is generally on the categories of pesticides being applied in a particular area.

The bottom_up approach is based on an inventory of the different crops for which pesticides are used. Estimations based on expert judgement are made of the expected amount of a given pesticide used for these various crops in a given period. Because the location and extent of the different crops often can be located through remote sensing, the geographical resolution of the estimation can be treated with greater accuracy. However, the approach is entirely dependent on local expert judgement of the volumes of pesticide used per crop variety.

3.2.3 Level of accuracy and resource requirements

Both the top-down and bottom-up approaches described above have their limitations, and a good fit between the estimation results and empirical data is not easy to achieve. The level of accuracy is affected by the availability and uncertainties in the data used for calculating volumes of pesticide used in each area. Another problem is that both methods can often only give the overall amounts used per pesticide category, not the distribution of emissions over the environmental compartments due to lack of data on partitioning ratios under local conditions.

To achieve this further level of detail, model calculations based on the pesticide application methods and the chemical properties of the active substance being applied are necessary. The well known Mackay model which incorporates only the physicochemical properties of the substance applied is sometimes used as a default approach.[8] However because pesticide fate and transport is a highly complex process affected by a large range of local environmental variables, the characterization of pesticide emission estimates can often be misrepresented. Proper assessments can only be made with both field and laboratory data, and making use of highly advanced mathematical models that endeavor to account for all environmental processes that could potentially affect the compound in question. Needless to say, such approaches are very time consuming and expensive and are generally out of the question for the practical purposes of an emissions inventory.

[8] A description of the MacKay model can be found in Mackay, K. (1995), “Evaluating the multimedia fate of organic chemicals.” Env. Sci. Technol. 25, pp. 427-436.

Example 3A: Emission estimation using top-down approach with given pesticide volume used in a particular region

Scenario:

Authorities are interested in estimating the annual emissions caused by pesticide application in Region X where particularly intensive agricultural activity takes place. The following data are available:

- only two types of pesticides (A & B) are used in Region X;
- the yearly volumes of these pesticides applied in Region X are known as 150 tonnes of pesticide A and 250 tonnes of pesticide B;
- partitioning ratios are available from the literature for these pesticides to estimate the amounts of pesticide VOC emitted to air, the residues absorbed by soil, and the amount likely to wash off by water run off;
- local technicians conducted a field test to calibrate these partitioning ratios to reflect local conditions;
- after calibration, the partitioning ratios for pesticide A are given as: 0.2 kg VOC emissions/kg of pesticide applied; 0.01 kg of non-soluble solid residue/kg of pesticide applied; 0.04 kg of soluble residue/kg of pesticide applied;
- for pesticide B, a water-based solution, the partitioning ratios are: 0.0 kg air emission/kg of pesticide applied; 0.02 kg of non-soluble solid residue/kg of pesticide applied; and 0.15 kg of soluble residue/kg of pesticide applied.

Sample emission calculation:

Using the above information, the emission calculation is straightforward and consists of simply multiplying the weight of applied pesticide (pesticide use data) by the corresponding partitioning ratio to obtain emission estimates for each environmental media (air, soil and water).

For pesticide A:

150,000 kg pesticide x 0.2 kg VOC emissions/kg pesticide = 30,000 kg of VOC emissions from pesticide A applications

150,000 kg pesticide x 0.01 kg solid residue/kg pesticide = 1,500 kg of non-soluble solid residue in soil from pesticide A applications

150,000 kg pesticide x 0.04 kg soluble residue/kg pesticide = 6,000 kg of soluble residue from pesticide A applications

continued.../

<u>Example 3A</u>, *continued*

For pesticide B:

250,000 kg pesticide x 0.0 kg VOC emissions/kg pesticide = 0 kg of VOC emissions from pesticide B applications

250,000 kg pesticide x 0.02 kg solid residue/kg pesticide = 5,000 kg of non-soluble solid residue in soil from pesticide B applications

250,000 kg pesticide x 0.15 kg soluble residue/kg pesticide = 37,500 kg of soluble residue from pesticide B applications

Estimation result:

To estimate the total emissions in Region X authorities have to decide whether they wish to add together the emissions from the two types of pesticides. In the case where the pesticide residues and emitted compounds are quite different for each pesticide type, keeping the estimates for each type separate provides more information on the compounds emitted than adding them together. It has to be borne in mind that the above method provides very little geographical resolution. This is illustrated by the fact that we have obtained only aggregate estimates for the whole of Region X. If pesticide application data were available on a finer scale, for example for each municipality in Region X, then a finer geographical resolution (by municipality) of the estimates would have been possible.

3.3 Excess Manure Production

Manure production by animal husbandry (e.g. cattle raising, piggeries, etc.) is in principle a component of the overall nutrient cycle and equilibrium of an agricultural system. If, however, animal husbandry is present on an industrial scale, ammonia emissions and emissions of nitrogen and phosphorus to water and soil from animal manure can cause environmental problems. Ammonia emissions, in particular, may be converted to nitric acid after atmospheric deposition and microbial conversion in the soil, making a significant contribution to total acid deposition in the soil in countries with intensive agricultural practices. In most countries, however, manure production does not disrupt the natural equilibrium of the nutrient cycle and its use as fertilizer remains an ecologically sound process.

3.3.1 Data needed

Data needed for manure production calculations are the number and type of animals, and the treatment methods being applied to the manure produced (i.e. composting, applied as soil fertilizer, discharged without treatment, discharged after treatment, etc.). These data should be apportioned as specifically as possible within the area being considered for the inventory. Appropriate emission factors for each type of manure/treatment method combination and manure characterization are also needed to estimate emissions of relevant pollutants caused by manure production. Some international emission factors are available from the literature but an accurate estimation will require cross checking with local studies (if available) due to differences in waste characterization and treatment methods between countries.

3.3.2 Estimation methods

Once specific manure production and treatment method data by area are obtained, the estimation consists of applying an appropriate emission factor for each type of manure/treatment method combination to estimate emissions of relevant pollutants per environmental media. For example, emissions of ammonia to air will require the multiplication of a specific emission factor (quantity of ammonia released per kg of manure) by the amount of manure spread over the land as fertilizer. To estimate the release of nutrients to water (N and P) from manure sources, a different emission factor must be used.

If local manure production exceeds the carrying capacity of the land, the treatment will include dewatering and drying of the material. These operations very often result in the incorporation of high concentrations of metals, for example copper in piggery waste in places where copper is added to pig feed. If the accumulation of heavy metals in soil from treated manure sources is to be estimated, yet a different emission factor must be used for that particular purpose.

3.3.3 Level of accuracy and resource requirements

The examples above illustrate the specificity of the emission factors used which causes the accuracy of this estimation technique to highly dependant on the quality of the available data and emission factors. Obtaining emission factors and reliable manure production, characterization and treatment data from scratch is both time and skill intensive and will probably require expert judgement and/or field tests. Once the data is obtained the actual estimation of emissions is fairly simple.

3.4 Burning of Waste Biomass

Burning of waste biomass is related to certain crops such as potato cultivation or orchards. In other cases biomass burning may be related to deforestation and land clearing for grazing or crop cultivation purposes. This is the case particularly in tropical forested areas where slash and burn agricultural practices are used or population pressure causes encroachment of forests. The smoke from biomass burning is likely to cause local air pollution problems due to the particulates and CO_2 emitted, and may contribute to the global greenhouse effect, particularly in the case of large scale burning occurring mostly in the tropics.

3.4.1 Data needs

Ideally, **statistical information on the quantity (weight) of biomass burned** should be obtained, but in practice it is seldom available. In the case of burning practices associated with particular crops, expert judgment and the experience of other countries could be used to produce an **estimation of the quantity of biomass burned**. The estimation would be based on knowledge of the quantity and location of these crops being produced in the country. In the case of large scale biomass burning linked to deforestation and land clearing, **remote sensing data and geographical information systems (GIS)** could be used to give an indication of the extent of burning from which an estimation could be produced.

3.4.2 Estimation methods

The estimation of emissions could proceed in various ways depending on the type of primary data obtained. For example, in the case of crop associated burning, the calculated total weight of waste biomass burned can be multiplied by an emission factor relating the quantity released of CO_2, particulates, and other air pollutants of interest per unit weight of waste burned, as in the following equation. The necessary emission factors can be obtained from the literature.

emission factor specific to biomass type and air pollutant	**x**	**biomass burned in area**	0	**emissions of air pollutant due to biomass burned**
(kg emissions/tonne burned)		(total tonnes burned)		(kg of air pollutant emissions)

Alternatively, if the primary data is obtained via remote sensing, it would usually consist of area (km^2) of forest or grassland burned. In this case a different emission factor would have to be obtained relating emissions expected from the burning of the vegetation mass in question per unit area burned. This emission factor would have to be multiplied by the total area burned, as indicated by the remote sensing data, by applying the following equation. An example of an estimation of this type is provided in Example 3B.

emission factor specific to vegetation type being burned	x	**total area burned**	=	**estimated air emissions due to biomass burned**
(tonne air emissions/unit km^2)		(total km^2 burned)		(tonnes of air emissions)

3.4.3 Level of accuracy and resource requirements

The uncertainties in the emission factors used, the fact that total combustion of the material often does not happen in practice, and the difficulties in the collection of reliable data on crop burning practices, particularly in the crop specific case described, cause the accuracy of this estimation technique to be low. However this method can be used to obtain rough estimates of air emissions due to burning.

Example 3B: Emissions from forest burning given total area burned

Scenario:

Authorities in City Y are interested in estimating the annual contribution of air pollutant emissions occurring in the vicinity of the city due to biomass burning. In the area surrounding City Y, this type of burning is due to tropical forest clearing for cattle raising and small scale agriculture. The incidence of these two informal activities has increased in the past several years and the air emissions produced are causing public health concerns in City Y.

The following data are available to city authorities:

- The forest department and local university have determined the following emission factors per unit area burned based on the type of vegetation prevalent in the region and its combustion profile: 30 tonne CO/km^2 burned, 60 tonne PM/km^2 burned.
- The annual estimate of burned vegetation area around City Y is 150 km^2.

Sample emission estimation and result:

Using the given data we can directly apply the formula in the text above to estimate the air emissions from the biomass being burned around City Y, as follow:

30 tonne CO/km^2 burned x 150 km^2 burned per year = 4,500 tonnes of CO per year

3.5 Combustion Emissions from Use of Tractors, Harvesters and Other Motorized Equipment

The emissions arising from motorized agricultural equipment include the major categories of air pollutants (VOCs, NOx, CO, SO_2, PM_{10}), the same air toxics mentioned for road vehicles and shipping (i.e. benzene, 1,3-butadiene, formaldehyde and acetaldehyde), and heavy metals such as Pb, Cr, Cd, Cu, and other metallic compounds present in fuel or lubricant additives. However the air emissions from the use of this equipment in most cases will only be relevant at the local level and will not represent significant contributions to national emissions relative to road vehicles.

3.5.1 Data needs

The data needed for estimating the combustion emissions from motorized agricultural equipment are analogous to those described for road vehicles. The **amount and type of fuel used by equipment category** would have to be obtained, as well as **appropriate emission factors** per engine type or equipment category.

Statistics about the fuel used by tractors and harvesters are rarely available. If no statistics are available, it is possible to relate the amounts of fuel used to the nature of the crop for which the motorized equipment is being used. Details about these crops can in many cases be derived from national statistics. This information, in combination with expert judgement, knowledge of farming practices and the types of equipment in use, can be used to estimate amounts of fuel consumed by equipment type. The emission factors by equipment class can be derived from the factors available for road traffic.

In countries where greenhouse farming is frequent, the amounts of fuel used for the heating of greenhouses are usually available from energy statistics. Emission factors for these greenhouse installations are usually available from the literature. If a rather clean fuel such as natural gas is used for greenhouse heating, the emission contribution of this activity is not likely to be significant.

3.5.2 Estimation methods

The principles for the estimation are similar to those presented for road vehicles, that is, an appropriate emission factor for each equipment category is multiplied by the fuel use estimated for that equipment category as follows:

emission factor for equipment category (kg emissions/unit fuel consumed)	x	**fuel consumed within area by equipment category** (total fuel used)	=	**emissions per equipment category** (kg of air emissions/ category)

These estimates can in turn be aggregated across agricultural equipment categories to obtain an estimate of total air emissions contributed by the use of motorized equipment used in agriculture within the inventory region.

3.5.3 Level of accuracy and resource requirements

The overall accuracy of the technique described is low given the numerous uncertainties in the emission factors and fuel use data. Calculation of the emission estimates is fairly simple but the amount of time needed to collect reliable data can be considerable.

4. SMALL AND MEDIUM SIZED ENTERPRISES (SMES)

4.1 Overview

What are the major sources types?

Small and medium sized enterprises (SMEs) can be divided into two categories for emission estimation purposes:

- enterprises engaging in industrial production process categories in which the bigger plants are commonly treated as point sources; and
- enterprises such as dry cleaners, bakeries or service stations whose activities are directly related to the population density in the area where they are located.

What are the major pollutants involved and their health and environmental effects?

Small scale industrial operations may be a source of all major air pollutant categories: VOC, NO_x, CO, SO_2, and PM_{10}. They also may be a source of discharges of water pollutants to public sewer systems. Small scale industrial operations associated with food processing, beverages, textiles, packing and distribution of foodstuffs, among others, are sources of organic waste and suspended solids. In addition to these common pollutants, operations such as leather tanning and textile and apparel industries usually discharge oil, phenol, Cr, and sulfide as liquid wastes. Other operations involving metal works and electroplating may discharge heavy metals such as Fe, Zn, Cu, Ni, Al, as well as oil, SO_4, NaOH, and CN depending on the particular metal worked and the types of chemical baths and brightening agents used. Cleaning operations involving solvents, oils and detergents also contribute to water pollutant discharge in sewers.

As illustrated by the above list, the range of pollutants discharged by small and medium sized industrial operations is very broad, and so are their health and environmental effects. Some of these effects have been described in previous sections associated with particular groups of these pollutants. The populations most likely at risk from these emissions are the workers themselves who may be exposed to these pollutants in high concentrations at their daily working environment, and the general population living in the vicinity of the operation/enterprise.

Why are small and medium sized enterprises treated as non-point sources?

The fact that small scale industrial operations tend to be part of the informal sector, and therefore too numerous and difficult to monitor and control as single point sources, represents a major reason for their treatment as non-point sources. With regard to air emissions, the USEPA (1991)[9] has recommended that sources emitting less than 10 tons of VOCs, or 100 tons of NOx, CO, SO_2, or PM_{10} per year be inventoried as non-point sources. But in practice no easy rule of thumb exists for countries to decide which scale of industrial operations should be treated as point sources and which as non-point sources for the purpose of an emission inventory. The key criterion is often pragmatism: authorities often decide based on the maximum number of industrial point sources they are able to handle individually, selecting only the larger plants for individual emission reporting and leaving the rest of the industrial sector's emissions to be estimated as non-point sources.

What is the relevance of these sources in the context of a national PRTR ?

In many countries, small and medium scale industrial operations, which most often operate informally, may represent a very significant combined source of pollutant emissions. This situation is aggravated by the fact that small and medium enterprises tend to be enmeshed in the fabric of the urban landscape and therefore may represent a significant source of exposure to pollutants for urban populations.

In general the contribution of emissions from small and medium sized enterprises will vary according to their particular industrial activity or production process. For sub-sectors like the chemical industry where the bulk of production takes place in large plants, the contribution of SMEs to the total emissions may be minor. For categories such as the graphic arts and printing industry, the number of small enterprises greatly exceeds the number of large plants and therefore SMEs will contribute the bulk of emissions. Emissions from SMEs engaged in services are generally minor, but there are exceptions like dry cleaning where the emissions of halogenated hydrocarbons usually represents a significant contribution to national emissions.

These examples illustrate that the relative importance of emissions contributed by SMEs will depend on the prevalence and types of SMEs in the country. However, given the size of the SME sector in most developing countries, accounting for these emission sources will be important to achieve an accurate and comprehensive emissions inventory.

[9] USEPA, 1991, "Procedures for the Preparation of Emission Inventories for Carbon Monoxide and Precursors of Ozone, Vol. I", Alliance Technologies Corporation, EPA Contract No. 68-D9-0173.

What are the potential challenges and resource requirements?

The calculation of appropriate emission factors per SME category is both time and skill intensive and usually requires expert judgement to adjust internationally available emission factors to local conditions. Obtaining an accurate estimation will often also require calibration and validation of the emission factors through field tests or surveys. Another challenge presented by the SME sector is that reliable production activity data for the various SME categories engaged in different production processes is often difficult to obtain. The informality of the SME sector in many countries often means that its activities are not included in official statistics and data collection efforts.

What are the general applications and uses of these estimates?

Detailed pollutant emission estimates per SME category may provide baselines from which to develop specific policy interventions aimed at this sector, which usually remains outside of government pollution management efforts due to its informal operation. The interventions that the availability of detailed emission baselines make possible include actions which address the supply chain and input substances used, pilot demonstration and diffusion of abatement techniques specifically geared to each SME category, and training on simple pollution control practices. A periodic estimation would require increased data collection from this sector and the gradual buildup of data bases for tracking the progress of SMEs and thereby the effectiveness of the policies deployed. SME emission estimates could also provide invaluable input for local level public and environmental health studies, particularly if the estimates are broken down with enough detail into individual chemical species. Such estimates could provide an important input into problem identification, priority setting, and local action.

4.2 Small and Medium Sized Enterprises in Industrial Sub-sectors in Which Larger Plants Are Commonly Treated as Point Sources

In some industrial sub-sectors, SMEs are engaged in similar production processes as the larger facilities, only on a smaller scale. Specific industrial sectors in which this situation is frequent are graphic arts/printing, chemical cleaning, surface coating operations, textile and apparel manufacturing, pottery and glassware manufacturing, fabricated metal products, food processing and canning, electroplating, and leather tanning, among others. Because the larger plants are normally treated as point sources, well defined emission factors relating emissions to actual production are usually available for these production processes or categories of industrial activity. This makes it possible to scale down the estimation methods used for the larger point sources so that they can be used for smaller scale enterprises undertaking similar production activities.

4.2.1 Data needs

In general, the estimation of emissions from small and medium sized enterprises engaged in different categories of industrial activity will require the collection of similar types of data. The first type are **emission factors specific to the industrial process** being examined. The second type consists of SME **production activity data**. Emission factors for the major standard industrial categories and processes are available in the literature.[10] These emission factors usually give the emissions from a given process in relation to the quantity of production (quantity of emissions per unit produced).

As a result of the emission reporting requirements of the US Emergency Planning and Community Right-to-Know Act of 1986, the USEPA has developed guidelines for the estimation of chemical releases for a variety of common industrial processes.[11] Even though these guidelines are intended for large point sources, many of the processes described are common within SME operations such as: electroplating; presswood and laminated wood products; leather tanning and finishing; textile dying; printing operations; rubber production and compounding; fibre manufacturing; spray, electrodeposition and roller coating operations; paper and paperboard manufacturing; wood preserving operations, etc. These guidelines and similar literature can be used to derive emission factors applicable to SME activities, bearing in mind that adjustments may be necessary due to the possible use of simpler technology, low penetration of abatement techniques, and other relevant differences according to the particular situation of each country.

The second type of data needed are production activity data indicating the amount of production associated with small and medium sized enterprises for each category of industrial process being considered within the inventory region. Because plant level production information usually is not available for small and medium sized companies, a topdown approach is generally used. This topdown approach uses nationwide production statistics and allocates a portion of total production to SMEs after accounting for the contribution of the larger operations to the total. This method can be used to obtain a rough calculation of production activity data for SMEs.

In many cases, however, national production statistics may not reflect informal production by small and medium enterprises, or the relation between total national production statistics and the processes used by small and medium enterprises will have to be provided by expert judgement or local activity surveys. An alternative approach, therefore, is to estimate production activity data from other statistics that could better reflect the localization of small and medium industrial activities. The sources of these statistics may be at the municipal or city council level, or from small trade associations, supplier and distributor groups, or any other available source of information on the SME sector.

4.2.2 Estimation methods

The principles for the estimation involve multiplying an appropriate emission factor, specific to the production process being used, by the production activity data (quantity of product

[10] For a comprehensive set of emission factors for air/water/solid emissions for common industrial activities please refer to Alexander Economopoulos, "Assessment of Sources of Air, Water, and Land Pollution. A Guide to Rapid Inventory Techniques and Their Use in Formulating Environmental Control Strategies". WHO, Geneva 1993 (WHO/PET/GETNET/93.1-B)

[11] See series (14 industry specific documents) published by USEPA (1988) under *Title III Section 313 Release Reporting Guidance*, "Estimating chemical releases from ...."

produced) in each particular category of industrial activity undertaken by SMEs, as shown in the following equation and as illustrated in Example 4A.

emission factor specific to the production process (kg emissions/unit product)	**x**	**total quantity of product produced** (total units produced)	=	**emissions per SME production process category** (kg of emissions per SME production process category)

The estimation has to be performed separately for each SME production process category since different emission factors would apply to different categories. Also, in order to achieve some degree of geographical resolution, the estimation would have to distinguish between groups of SMEs located in different areas within the inventory region. These estimates can in turn be aggregated across production process categories to obtain an estimate of total emissions contributed by SMEs within the inventory region. In general, the geographical resolution of this approach will be fairly low given the difficulty of obtaining reliable and localized production activity data for SMEs.

In some cases it may be possible to define emission factors on a "per employee" basis using expert judgement or local surveys of particular SME industrial sub-sectors or production processes. If "per employee" emission factors can be derived, and if data on the number of employees per each SME category is more reliable than production activity data, then this approach may yield a more accurate estimate. In countries where statistics on the number and location of workers engaged in SMEs are available, the "per employee" approach would enable a finer geographical resolution of the emissions estimated for SMEs.

The estimation of emissions on a "per employee" basis is illustrated as follows:

emission factor specific to the production process (kg emissions/employee)	**x**	**total number of employees engaged in this SME production process category**	=	**emissions per SME production process category** (kg of emissions per SME production process category)

The estimation, which is further illustrated in Example 4B, has to be performed separately for each SME production process category since different categories will have different "per employee" emission factors.

This method is often the only possibility for obtaining at least an initial estimation of emissions. The Netherlands, for example, uses this method to obtain an overall picture of emissions contributed by different branches of industry. The accuracy of the result is mainly determined by whether the technology and abatement techniques of the larger companies for which data is available are comparable to those used by the smaller facilities. The degree to which this is the case is different for different branches of industry.

Another down scaling approach can also be used for rough emission estimates from SMEs, in particular industrial sub-sectors in which an acceptable number of large plants are already inventoried. The approach, which is illustrated in Example 4C, consists of simply down scaling the emissions from the large plants inventoried as point sources by a factor proportional to the relative SME/large plant composition of the sector taking into account differences due to use of fewer abatement techniques and simpler technology used in the SME component.

4.2.4 Level of accuracy and resource requirements

The specificity of the emission factors used, along with the uncertainties with regard to SME production activity, employee data and/or geographical distribution, cause the accuracy of these estimation technique to be highly dependant on the quality of available data and the degree to which the emission factors are suited to the SMEs in the inventory area. Obtaining these data and emission factors from scratch is both time and skill intensive and will probably require expert judgement and/or local field surveys. Once the data is available, the actual estimation of emissions is fairly simple.

Example 4A: Emission estimation for a city with two types of SMEs for which production data and process based emission factors are available

Scenario:

Authorities in City Z are interested in estimating the annual emissions contributed by the sizable SME sector in the city. The following data is available:

- City Z's SMEs are only of two types: galvanizers and surface coaters.
- Production data is available for the two types of SMEs as follows: the annual production of galvanizers is 1,000 tonnes of galvanized sheet metal; the annual production of surface coaters is 450 tonnes of coated surfaces.
- From the literature and local field studies of the galvanizing and surface coating production processes, the following emission factors were obtained: For galvanizers: 0.8 kg of heavy metals liquid waste/tonne of product; and 0.07 kg of oil waste/tonne of product. For surface coaters: 80 kg of VOC/tonne of product; and 0.06 kg of oil waste/tonne of product.

Sample emission estimation:

Given the above data, the formula in the text can be used to yield the following emission estimates from SME production processes in City Z:

For galvanizing SMEs:

0.8 kg heavy metals/tonne product x 1,000 tonnes/year = 80 kg of heavy metal liquid wastes discharged per year

0.07 kg oil waste/tonne product x 1,000 tonnes/year = 70 kg of oil waste discharged per year

For surface coating SMEs:

80 kg VOC/tonne product x 450 tonnes/year = 36,000 kg VOC emissions per year

0.06 kg oil waste/tonne product x 450 tonnes/year = 27 kg of oil waste discharged per year

Estimation result

The above emission results can be aggregated across galvanizers and surface coaters to obtain the total annual emission contribution of the SME sector in City Z as follows:

80 kg of heavy metal liquid waste discharges;
70 + 27 = 97 kg of oil waste discharges, and
36,000 kg of VOC air emissions

Example 4B: Example of top-down emission estimation for dry-cleaning industries

The overall amount of tetrachloroethylene used in the dry cleaning sector is usually available as a nationwide figure. This amount can be divided by the number of people working in the dry-cleaning sector to obtain an emission factor per employee which can be used at the local level to estimate emissions from dry-cleaning industries. If data is available on the actual amount of clothing that is dry cleaned on a nationwide as well as local scale, a finer approximation can be accomplished.

Example 4C: Example of top-down emission estimation for the printing industry

The detailed registration of a few big printing industries is usually available, as well as data on their production and their number of employees. This information can be used for calculating an emission factor for the printing industry either on a per unit of production or per employee basis which can then be used to estimate emissions from the printing industry at the local level.

4.3 Small and Medium Sized Enterprises Whose Activities Can Be Directly Related to Population Density

SMEs in this category are those which are engaged in process and service activities such as dry cleaners, bakeries or service stations. Given that the SMEs in this category typically serve residents of the surrounding neighborhood, their activities can be directly related to the population density in the area where they are located.

4.3.1 Data needs

In general, the estimation of emissions from small and medium sized enterprises whose activities correlate well with population can be based on **"per capita" emission factors** and **population data**. Deriving per capita emission factors (quantity of emissions per inhabitant) requires the availability of data relating quantity of pollutants released to the size of the population in the surrounding area or population density. If sufficient data is available to derive per capita emission factors in some localities, their use can be extended to localities where no data are available, provided that adjustments are made for any substantial differences in activity levels that may exist between regions.

The other type of data needed for the estimation are population density statistics which are generally available in most countries from population census or municipal or city registries.

4.3.2 Estimation methods

The estimation of emissions from SMEs whose activities can be directly related to population density involves multiplying an appropriate per capita emission factor specific to the SME activity being considered by the total population in the area being considered, as follows:

per capita emission factor (kg emissions/inhabitant)	x	**total population in area being considered**	=	**emissions per SME activity in area being considered** (kg of emissions per SME activity or category)

Alternatively, population density data can be used by applying the following equation and as illustrated in Example 4D:

per capita emission factor (kg emissions/ inhabitant)	x	**population density in area being considered** (number of inhabitants/km^2)	x	**total area** (total km^2)	=	**emissions per SME activity in area being considered** (kg of emissions per SME activity or category)

Both emission estimation formulations given in the tables above assume that the population density is constant in the area being considered, therefore the total inventory area should be broken down into smaller areas in which the population density is approximately uniform and then separate estimations should be performed for each of these smaller areas. This allows a more accurate geographical resolution of the estimated emissions. Otherwise a rough estimate for the total area being considered can be obtained simply by multiplying the appropriate per capita emission factor by the total population without attempting a finer geographical allocation of estimated emissions within the inventory area.

The estimation has to be performed separately for each SME production process category since different per capita emission factors would apply to different SME categories engaged in different activities (i.e. bakeries, dry cleaners, etc.).

4.3.3 Level of accuracy and resource requirements

Like other techniques described previously, these estimation techniques are highly dependant on the quality of the emission factors, thus the specificity of the per capita emission factors used for each SME production process category will determine the accuracy of the estimation results. Deriving appropriate emission factors from the literature and adjusting them to local conditions requires time and skill. Expert judgement and local field surveys may also be needed. On the other hand, obtaining population data should not represent a major obstacle for most countries. Once the data is available the actual estimation of emissions is fairly simple.

Example 4D: Emission estimation for a city with two types of SMEs for which per capita emission factors are available

Scenario:

Authorities in City Z are interested in estimating the annual emissions contributed by the sizable SME sector in the city. The following data are available:

- City Z's SMEs are only of two types: dry cleaners and auto repair.
- Local field studies and census data reveal that on average there are 1 dry cleaning SME and 2 auto repair SMEs for each 5,000 inhabitants in City Z.
- The same studies have determined that on average dry cleaning SMEs emit 10 tonnes of VOCs per year and auto repair SMEs discharge 12 tonnes of heavy metals-oil contaminated liquid waste per year.
- City Z has a uniform population density of 500 inhabitants/km^2 and a total extension of 150 km^2.

Sample emission estimation:

Given the above data, a per capita emission factor for each SME can be calculated as follows:

For dry cleaning SMEs:

1 dry cleaning SME/5,000 inhabitants x 10 tonnes yearly VOC emissions/dry cleaner = .002 tonnes average yearly VOC emissions/per capita from dry cleaning SMEs

For auto repair SMEs:

2 auto repair SMEs/5,000 inhabitants x 12 tonnes yearly liquid waste discharge/auto repair = .0048 tonnes average yearly heavy metals-oil waste from auto repair SMEs

Using the formula in the text, the calculated emission factors and population density data may be combined to yield emission estimates from dry cleaning and auto repair SMEs in City Z:

For dry cleaning SMEs:

.002 tonnes VOC emissions/per capita x 500 inhabitants/ km^2 x 150 km^2 = 150 tonnes of VOC emissions per year

For auto repair SMEs:

.0048 tonnes heavy metals-oil waste/per capita x 500 inhabitants/km^2 x 150 km^2 = 360 tonnes of heavy metals-oil liquid wastes discharged per year

continued...

Example 4D: ***continued***

Estimation result

Thus, the total annual emission contribution of the SME sector in City Z is estimated to be:

150 tonnes of VOC emissions per year by City Z dry cleaning SMEs; and
360 tonnes of heavy metals-oil liquid wastes discharged per year by City Z auto repair SMEs.

80 kg of heavy metal liquid waste discharges;
70 + 27 = 97 kg of oil waste discharges; and
36,000 kg of VOC air emissions.

5. NATURAL SOURCES

5.1 Overview

What are the major sources types?

Biogenic and geothermal phenomena may also cause emissions of certain substances to various environmental media. Living organisms such as vegetation and microbes are examples of biogenic sources, whereas volcanoes are geothermal sources of pollutants that can have impacts even on a global scale depending on the magnitude of the eruption. The oceans also play an important part in the overall natural cycle of atmospheric gases, including the contribution of natural biogenic emissions from the phytoplankton.

What are the major pollutants involved and their health and environmental effects?

VOC emissions occur naturally from vegetation and are emitted from the leaves and needles of trees. VOC emissions from vegetation are estimated to account for more than 50 percent of total hydrocarbons emitted to air in the United States, although the average intensity (quantity of emissions per unit time, unit area) of these emissions is 20 times less than in urban and industrial areas.[12] Vegetation is also found to emit numerous organic compounds such as 2-methyl-1,3-butadiene, commonly known as isoprene (C_5H_8), and ∀- and ∃- pinene ($C_{10}H_{16}$), and 1,8 cineole or eucalyptol.[13]

Soil processes, particularly in grasslands, may be a source of NOx emissions, although on a scale three orders of magnitude smaller than anthropogenic sources. VOC and NOx emissions from biogenic sources can contribute to the production of oxidants in rural and urban areas, and some studies suggests that the effectiveness of oxidant abatement strategies in metropolitan areas based on the reduction of anthropogenic hydrocarbon emissions may be significantly overestimated if naturally emitted organic compounds are neglected.[14] Other soil processes, especially in anaerobic situations, can contribute to emissions of hydrogen sulfide or nitrogen compounds. All of these biogenic emissions combined represent a source of organic acids which can contribute to or even dominate regional acid deposition.[15] Finally, emissions of air pollutants (particulates, ash, SOx, and other gases) from volcanic eruptions can affect the atmosphere on a worldwide scale, aside from the frequently devastating effect of eruptions at the local level.

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[12] Lamb, et al. 1987, as cited in Australia EPA/ Dames & Moore. Emissions Estimation Techniques Report, Appendix F, Vol 1. pp.58, 1996.
[13] Australia EPA/ Dames & Moore. Emissions Estimation Techniques Report, Appendix F, Vol 1. pp.58, 1996.
[14] Lamb, et al. 1987, as cited in Australia EPA/ Dames & Moore. Emissions Estimation Techniques Report, Appendix F, Vol 1. pp.58, 1996.
[15] Jacob & Wofsy '88; Ayers & Gillet '88, as cited in Australia EPA/ Dames & Moore. Emissions Estimation Techniques Report, Appendix F, Vol 1. pp.58, 1996.

Why are natural sources treated as non-point sources?

Biogenic sources are intrinsically diffuse and thus are treated as such for emissions estimation purposes. Volcanoes and other geothermal phenomena can be treated as either point- or area sources depending on the extent of the area giving rise to the emissions.

What is the relevance of these sources in the context of a national PRTR?

Natural sources are not generally accounted for in the context of national PRTR systems because the intensity or areal flux of their emissions is generally small relative to anthropogenic sources. In general, emissions from vegetation or soil only contribute to the background concentrations of particular pollutants. Exceptions may include certain densely wooded areas where "blue haze " may be present. Emissions from volcanoes, even though often relevant on a global scale, are not susceptible to policy action and are therefore rarely treated in a PRTR except perhaps for certain locations where a relatively constant background emission from geothermal phenomena may be present. The same applies for the emissions from oceans which are part of the natural cycle of atmospheric gases.

5.2 Estimating Emissions from Natural Sources

5.2.1 Data needs

The calculation of emissions from natural sources requires specific data particular to each local situation. In general two types of data are required: **parameters describing the particular natural phenomena causing the emissions** and **location data describing the geographical extent of the source**. For example, emissions from soil and vegetation are determined by several factors including the properties of the specific soil or vegetation type, mean temperatures, regional meteorological conditions and other variables. Remote sensing and land use data are also required for a complete estimation of emissions from these sources. Estimation of emissions from geothermal sources may be undertaken from available geographic information and with the help of emission factors available from literature.

5.2.2 Estimation methods

The specificity of the emission estimation methods used for the various types of natural sources parallels the data requirements described previously. For example, for estimating VOC emissions from vegetation several approaches exist. The vegetative index approach consists of developing an index, representative of vegetation cover, from interpretation of satellite imagery and field surveys of actual canopy leaf volume. The appropriate vegetative index, ranging from negligible to densely wooded vegetation, is assigned to each grid cell within the inventory region. VOC emissions are then estimated based on the vegetation cover index.

Another approach makes use of highly specific VOC emission factors which require information on vegetation and soil type, leaf temperature and other variables depending on the particular model used. The emission factors are then applied on detailed maps of vegetation coverage. The use of these methods is constrained by the availability of local data and previous studies.

The estimation of NO_x emissions from soils involves the use of models corresponding to land use categories. These emissions arise from microbial and chemical processes involving nitrification/denitrification cycles which are highly dependent on temperature. The approach used by most NO_x soil emission models consists of developing empirical relationships based on field tests with the input variables being land use and soil temperature.

5.2.3 Level of accuracy and resource requirements

Given the specificity of the data and emission factors required, the accuracy of these methods depends entirely on the level of uncertainty in the required data inputs. For example, regarding vegetation types, some degree of aggregation and simplification of categories is always required for practical purposes. Local field samples or adjusted international data may not always be representative of the inventory region. Likewise the estimation of mean soil or leaf temperatures is in itself not entirely reliable since these parameters undergo significant natural variability. Expert judgement and the availability of local studies is generally required for these estimations.

Part C: Non-Point Estimation Data in the Context of a National PRTR System

1. INCORPORATING NON-POINT SOURCE EMISSION DATA IN A NATIONAL PRTR SYSTEM

1.1 General Considerations

Deciding on the inclusion of non-point source emissions in the national PRTR

In the process of establishing a PRTR, it is important to undertake an overview of national environmental problems, the economic activities which contribute to them, and the substances or pollutants involved. The environmental and health-related problems of priority concern, and the economic activities which contribute to them, will differ from one country to the next. Thus the nature and focus of a national PRTR will vary in accordance with each country's particular situation.

When considering the inclusion of non-point source emissions in a national PRTR system, a first step should be to conduct an inventory of the information available on the various economic activities which act as sources of pollutants. How many of them can be regarded as point sources? For those which are likely to be treated as non-point sources, is the amount and quality of the available information sufficient for a first estimation of total emissions?

For non-point sources in general, or for point sources for which sufficient information is not available, an inventory should be made of relevant statistical data or marketing information that could be used to construct emission estimates. Emission factors suitable for calculating emissions should be derived either from the literature or through comparisons with situations elsewhere. A general approach for conducting such an inventory involves the following three steps:

- First, a quick gathering of available information and data relevant to emissions estimation for each economic activity under consideration should be carried out, without trying to achieve optimal accuracy. This material should be evaluated in order to determine priority sectors as well as economic activities for which more detailed information will be needed in order to estimate emissions. Areas for which information is missing should also be clearly identified.

- The next step is to generate emission estimates with the collected information for the priority sectors identified in the first step.

- The third step is to verify the accuracy of these emission estimates through a verification programme involving the use of modeling approaches and/or drawing upon available measurements of environmental quality. An acceptable fit of the emission estimates with other external measurements indicates that indeed the available information is enough to provide suitable estimates.

For the sake of efficiency, is important to avoid spending a lot of effort in calculations for sources that may be irrelevant at a later stage.

Management of non-point source emissions data in the context of a PRTR

The estimation of emissions arising from non-point or diffuse sources will generate a national data set for these sources. To assess total nationwide emissions, this non-point data set needs to be "layered" on top of the point source PRTR data. These two data sets are structurally different. The non-point data set consists of emission estimates associated with particular geographical areas, the size of which is usually determined by the particular source being examined, and in some cases which might correspond to particular landscape features such as roads, an inland shipping route, a city, a water body, etc. In comparison, the standard point source data set consists of PRTR emission data associated with single points in geographical space.

Because the two data sets are structurally different, software aids must be used that enable the layering of the non-point or diffuse source emission estimates with the standard point source emission data by geographically referencing the two data sets and combining them in an appropriate "combined emissions" data set or "aggregate emissions map." The tools developed for geographical information systems (GIS), as described below, provide the user with instruments essential for an effective layering of these two data sets in order to arrive at an overall picture of national emissions.

Another important aspect for correctly incorporating the non-point source emission estimates into the larger national PRTR system, and in fact for the overall accuracy of the whole PRTR exercise, is a good organization of the data collection, handling and information flows between local, regional, and national levels. A precise definition of data estimation, collection, and management procedures at all levels is of utmost importance. Local and regional staff need to be adequately trained, *inter alia*, on how to perform the data aggregation that may be required at the local and/or regional level before relaying the data to the central database. A thorough agreement on definitions (i.e. measurement units, source and pollutant categories, etc.) and methods to be applied is essential both among government staff as well as towards other actors who may be involved in the system in various capacities (i.e. individuals supplying information or estimating emissions from their plants, consultants assisting with data collection and emissions estimation, etc.)

Additional analyses which can be performed on emission estimates

In general, for emissions arising from non-point sources, the estimation techniques described in Part B of this document are sufficient to construct an aggregate emissions estimate for each particular area in which emissions of this nature are taking place. This is often all that is required for inventory (i.e. PRTR) purposes. However for further evaluation of these emission estimates, including for instance the diffusion of these emissions away from the area from which they originate, modeling of pollutant fate and transport becomes necessary. In cases where information is required on the ultimate fate of the inventoried emissions in the environment, the use of computer modeling techniques can provide insight into the transport, treatment, and transformations undergone by particular pollutants in their receiving media

(i.e. air, water and soil). However, it should be kept in mind that such techniques are very intensive in terms of data, computer analysis and professional time.
Detailed analyses of fate and transport usually fall outside the scope of the basic inventory function of a PRTR. However, some countries have included in their PRTR systems additional levels of analytical capability. These analytical capabilities involve software aids that facilitate the analysis of the raw emission inventory data for a variety of environmental management and policy purposes. These components can be thought of as analytical modules appended to the basic PRTR emissions database and inventory system.

1.2 Useful Tools

In the context of estimating emissions from non-point sources within a national PRTR system the following tools are frequently used:

- **Geographical information systems (GIS)**

The economic activities considered as non-point sources of emissions in the context of a national PRTR are typically located within 'governmental' as well as 'technical' boundaries. The governmental boundaries refer to provinces, towns, water boards and other responsible authorities. The technical boundaries relate to those used in the context of modeling applications, spatial planning, etc. For example, in air pollution modeling a grid cell system is needed, whereas for water pollution modeling relevant watershed areas are defined.

The development of geographical information system (GIS) tools has solved the problems associated with identifying and referencing locations which are described under these different systems. There are several GIS software packages available which allow information layers to be combined and subdivisions made with the relevant non-point source data. Digitalization of line and area elements in the data of course must first be done. In practice the grid coordinates are the starting point based upon which other data can be incorporated. For example, some tools are available which enable the user to link addresses (e.g. of facilities) with grid coordinates or grid cells. If this is not the case, the economic activities acting as non-point sources first must be located on maps so that the coordinates of the activity can then be introduced into the system. The GIS tools can also add labelling and other additional information for the digitalized governmental or technical boundaries.

- **Methods for estimating emissions at the source vs. emissions into the environment**

Is important to distinguish between emissions localized at the source and emissions dispersing into the environment. For emissions into air the source is usually also the place where the emission enters the environment. For emissions into water, and to a lesser extent for solid waste emissions, this is often not the case. In a PRTR, policy applications targeted at sources require information on the emissions at the source, e.g. for source monitoring. Policy applications focusing on environmental quality monitoring, on the other hand, require information on the emissions as they disperse into the environment. This often necessitates the development of a module describing the transport and treatment of the emissions, for example for wastewater, solid waste, or other specific emission flow under consideration. In many cases, associated emission flows will also need to be considered. For example in the case of wastewater, some diffuse contribution is also provided by emissions from storm sewers, emergency outlets or low quality sewer systems. In modeling emission flow and dispersion into the environment, care should be taken that the same emissions are not reported twice.

A related problem relates to the distinction between primary and secondary pollutants, which occurs for example in the deposition of air pollutants or leaching of polluted soil. In such cases, the same pollutant contributes twice to emissions into the environment, once when it is originally emitted and a second time through deposition or leaching after it has been released into an environmental compartment. The figures considered in these estimations are usually produced by models, and care should be taken to present the difference between the secondary pollutant flows and the primary emissions.

- **Models for calculating the distribution of emissions over the different environmental compartments**

For several economic activities which act as non-point sources, the environmental compartment to which the emissions should be attributed is not always clear. For instance, this is the case with several pesticide applications, as well as for lead from motorcar exhaust. There are several models available for making these calculations. However these models usually use assumptions about particle size or application techniques which may be rather difficult to establish for a given situation. A very simple model which uses only the properties of the substance in question is the Mackay model. However, this model is only suitable as a default method.

- **Composition profiles for standard mixtures**

Some of the emissions produced by an activity are in fact mixtures of individual chemical compounds. Some of these compounds may be individually relevant for policy makers. This is the case for hydrocarbons from motorcars, for example, or for PAHs which arise from several processes and activities. Incorporating the whole list of possibly interesting substances in the database is not very efficient but composition or speciation profiles can be used to desegregate an estimate for a pollutant category into its individual components by chemical species. In this way, separate modules containing process-related profiles of the pollutant mixtures can be developed and used whenever individual chemical species have to be reported.

- **Methods for estimating the accuracy of emission factors and emission estimations**

In order to compare the quality of the different data to be used for emission estimation, it is important to clearly define the quality criteria. A simple classification that works in practice originated from U.S. EPA and is now applied in the EMEP/UNECE Atmospheric Emission Inventory Guidebook.[16] This classification uses the following definitions:

A : An estimate based on a large number of measurements made at a large number of facilities that fully represent the sector.

B : An estimate based on a large number of measurements made at a large number of facilities that represent part of the sector.

C : An estimate based on a number of measurements made at a small number of representative factories, or an engineering judgement based on a number of relevant facts.

D : An estimate based on a single measurement or an engineering calculation derived from a number of relevant facts and some assumptions

E : An estimate based on an engineering calculation derived from assumptions only.

It is important to document the data sources and expected level of accuracy that enters into the construction of any emissions estimate. In this way a measure of the uncertainty associated with each estimate can also be reported, along with the estimate, to give the user a more objective picture.

2. SOME PRACTICAL EXPERIENCES ON THE INCORPORATION OF NON-POINT SOURCES IN A NATIONAL PRTR: THE NETHERLANDS EMISSION INVENTORY SYSTEM

2.1 Development of the Netherlands PRTR System

In The Netherlands, the first steps for the establishment of an integrated PRTR were made as early as 1974. Over the years, the system has gradually developed into a tool which is used in direct support of national policy. In 1989, the National Environmental Policy Plan made an important contribution to this development, defining groups of priority emission sources and emission goals or targets to be reached for each of the groups. The plan also defined a series of environmental themes reflecting various policy priorities as well as indicators for each of those themes. The PRTR system was adapted to reflect and support this overall policy approach. Other adaptations or additions to the PRTR occurred as new data analysis tools became available or in response to new requests from international, national and regional authorities. This process of adapting and improving the PRTR system is ongoing.

In 1992 the three ministries concerned with environmental problems decided that the Emission Inventory Database should become the national database from which all information about emissions should be provided to the users. Based on this decision, a

[16] EMEP/UNECE Atmospheric Emission Inventory Guidebook. Prepared by the EMEP Taskforce on Emission Inventories, available from European Environmental Agency (Kongens Nytorv 6 Kopenhagen, Denmark).

structure was developed in which the three ministries (Housing, Spatial Planning and the Environment, Traffic and Public Works, and Agriculture) and their supporting institutes, work together with the National Institute for Public Health and the Environment, Statistics Netherlands and the organization TNO which has been providing technical support during the whole PRTR development process. These activities are coordinated by the Environmental Inspection who is responsible for the final products.
Every year a national report is produced by several expert teams in which the partners are represented. The teams report to a central committee chaired by the Environmental Inspection. The data accepted by the partners are used for actualization of the database and are available to the public.

2.2 Key Features of the Netherlands PRTR System

2.2.1 Inclusion of point source and non-point source data

The Netherlands PRTR is operated as a single system incorporating various tools for different applications and categories of sources. The distinction between "Individual registration" for point sources and "Collective registration" for non-point and diffuse sources is only related to the organization of the data collection process. In general, the point sources have a more accurate indication of location and the emissions data are directly derived from measurements. For non-point sources, various kinds of data are used to estimate emissions depending on the particular type of source in question. Aside from this there in not a sharp borderline between the data input systems for point and non-point sources.

2.2.2 Target groups and environmental themes

In the National Environmental Policy Plan the different emission sources were aggregated in so-called target groups, each comprising a different source category. With representatives from these target groups (i.e industry representatives, etc.) agreements were established in which the reduction goals for the coming years were defined. Environmental themes reflecting environmental policy priorities in The Netherlands were also defined, and an indicator system developed to enable the policy makers to monitor progress towards these policy goals.

The ultimate goal of any environmental policy should be to improve the quality of the environment. The environmental themes provide a tool for monitoring these improvements. The only way to achieve results, however, is to direct efforts at the source of the pollution, i.e. the target groups. The PRTR system can be used to link or relate the target group emissions with improvements/deterioration of the indicators for various environmental policy themes. In this way, the PRTR is used as an environmental management tool in The Netherlands.

Target groups (source categories)

- **Refineries**

All refineries in The Netherlands are treated as point sources. The main emissions are determined at the plant itself. The information is introduced into the general system using tools like the hydrocarbon profiles or the metal content of crude oil.

- **Power plants**

All power plants are treated as point sources. The emissions are based on measurements at the stacks and are supplemented by emission factors or profiles for individual hydrocarbons.

- **Waste disposal**

The waste burning plants are treated as point sources. The emissions are measured at the stack. The landfills are individually located in the system on a 500 x 500 meter grid basis but their emissions to air and water are calculated from a model using yearly statistical information about the amount and type of wastes and emission abatement measures taken.

- **Industry**

The 700 biggest companies are treated as point sources. They are present in the system with individual emissions which are either measured or calculated with emission factors. The data may be provided by the companies themselves, or measured by TNO who gathers the information on contract from the Ministry. For emissions into water, the majority of the information comes from the responsible authorities who have extensive measuring programs. In the near future only the 300 biggest companies will be obliged to provide data in a standardized format. A verification program is being developed.

For profiles and external wastewater treatment, the tools from the general system are used. The other 40,000 industrial companies are identified by name and address, activity code and number of employees, and the emissions are generally calculated by the task groups mentioned above in terms of their contribution to nationwide production. The grid location is derived from an available address/grid tool. The facilities are also connected to the wastewater transport and treatment module (by hand so far). The total database contains about 400,000 companies, but the greater part is in the trade sectors. A discussion about their contribution to pollution is still going on.

For practical reasons, the emissions from a small fraction of the industrial activities are calculated in relation to population density. Examples include bakeries, garages and small dry cleaning facilities. At the time when the general industrial address database was not yet available, more industrial activities were linked to population density, or for activities located in certain regions, industrial areas or town centres. The emissions for the smaller companies are at the moment extrapolated from the point sources in the same sector nationwide by their contribution to total production, and localized by assuming a linear relationship with the number of employees. This approach however needs to be improved for some industrial branches. A project has been initiated by Tebodin, TNO and Statistics Netherlands in which analyses of the different industrial branches will be made to determine the representativeness of the larger companies as compared to the SMEs and to assess the contribution of the SMEs to total emissions. A possible outcome of this work may be the development of emission factors which are related to company size.

- **Agriculture**

Agriculture is treated as a non-point source. The main pollution sources in The Netherlands are pesticide use and excess manure production, with minor sources like harvesting machines and tractors. All activities are attributed to a 500 x 500 meter grid. Information comes from a number of sources which in some cases are not fully consistent. Pesticide use comes from a combination of sales figures through two enquiries using different selections. The relation with the individual crops is provided by agricultural consultants, the distribution over the different compartments is provided by a model from an institute related to the agricultural university. The location is mainly based on remote sensing information and topographical maps. The task group mentioned above reaches consensus about the optimal figures for a given year. Figures about the number of cattle come from the same statistics mentioned above but discussions about the penetration of abatement techniques and their effectiveness still need some expert judgement.

- **Traffic and transport**

Traffic is treated partly as a line source and partly as a non-point source. For the main roads, traffic intensities for different types of cars are measured on a regular basis. The locations of these roads are included in the system in digitalized form and emissions are calculated by using emissions factors per car/km for the relevant driving mode. The rest of the emissions from road traffic is calculated top-down by Statistics Netherlands using fuel statistics and some enquiries about car use by consumers. These emissions are located by relating them to the population density.

Emissions from sea-going and inland shipping are calculated from data from bridges and locks or harbour information. Recreational shipping is still mainly estimated by expert judgement. The railway company has an excellent database which provides all relevant information. Calculations for airports are based on information from the individual airports and international emission factors.

- **Consumers**

Data on the location of different types of houses on a 500 x 500 meter grid are provided by a joint project from the Postal Service, Statistics Netherlands and the National Planning Office. They locate addresses with an indication about the sort of activity belonging to the address. A simple adding program provides the number of houses. The number of inhabitants is related annually to the number of houses from information about the number of inhabitants per town. In an earlier stage the total number of inhabitants per town was distributed over the relevant areas using assumptions about population density in certain types of areas (town-centre, nineteenth century area, suburb, etc.). A great number of household and consumer-related activities are related to the population density. Some give only minor contributions, while others like solvent use or paint application are relevant on a national level.

- **Transport and treatment of wastewater**

Data for this target group, which includes emissions from storm sewers, rainwater outlets and effluents from wastewater treatment plants, are in a separate module in the PRTR database.

- **Production of drinking water**

This is a target group of minor importance. Discussions about the aspects to be monitored are ongoing.

- **Trade, services, government and research organisations**

This is a target group that is mainly linked with other activities. Special monitoring targets are not yet defined.

- **Nature**

While this is not an official target group, definition and incorporation into the database is necessary for achieving the complete picture. Data about natural areas are derived from topographic maps combined with satellite information. Emission factors for hydrocarbons from trees require a breakdown among the different types of trees. At the moment this is provided by a combination of a rather old statistics from 1982 and satellite data. Other interesting areas like wetlands are located from topographical maps. All data from these maps will be available shortly in a digitalized form from the Topographic Service.

Environmental themes

As previously mentioned, the PRTR emissions data for the above target groups have to be interpreted in the light of indicators tracking the evolution or trends in policy targets defined for each environmental theme. The following environmental themes have been identified in The Netherlands:

- **Climate change**

The main substance is of course carbon dioxide emitted mainly by power plants, traffic, and spatial heating. Other contributions come from methane, sources of which include landfills, ruminants and anaerobic processes, and dinitrogenoxide which arises from certain industrial processes, agriculture, and some natural processes.

- **Acidification**

The primary substance of concern with regard to acidification has always been sulfur dioxide from combustion processes, with nitrogen oxides from traffic and industry in second place. In The Netherlands, ammonia from excess manure is an important source in particular because the cattle concentrations are located near the scarce woods.

- **Eutrophication**

Eutrophication of lakes and rivers by excess phosphorus and nitrogen compounds is an especially important problem for The Netherlands. The cause is the great number of rather shallow lakes which are very vulnerable to this sort of pollution. Since the use of phosphorus compounds in detergents has been forbidden, agriculture has emerged as the main source, combined with remobilization of previously disposed sludges.

- **Dispersion**

Dispersion is a rather broadly defined theme which covers the entry into the environment of all undesired substances. In practice, the indicator used is mainly based on pesticide use by agricultural and, to a limited degree, non-agricultural activities.

- **Waste disposal**

The problems around waste disposal are rather specific for The Netherlands, as the space available for landfills is very limited due to the high population density. Activities are directed at reducing the amount of solid waste by consumers and stimulating reuse.

- **Disturbance**

Disturbance is a theme directed at reducing noise and odors. Noise abatement measures are directed at airports, main roads and sometimes at special industrial activities. Odor reductions are relevant near certain industrial activities as well as in areas where cattle raising with excess manure production is present. Criteria for the intensity of the problem are the number of people exposed to certain levels of noise and/or odors.

- **Dehydration**

While The Netherlands is a rather wet country, there are still areas where the use of water for agriculture or industry has caused the lowering of the groundwater level below acceptable limits. The resulting degradation of natural areas has made this a relevant theme in certain areas.

- **Squandering**

This is an environmental theme that has a lot to do with public awareness. There is a close relationship with life-cycle projects and efforts to stimulate reuse of wastes.

All of the above environmental themes are linked with indicators which are based on the contribution of individual substances to the general theme indicator. This provides the policy makers with a tool to monitor the effects of the environmental policy on the quality of the environment.[17] A more in-depth discussion of the various policy applications that are possible by relating target groups of sources and the evolution of environmental theme indicators can be found in The Netherlands Emissions Inventory annual report.

[17] A. Adriaanse, Environmental policy performance indicators.(1993) SDU printing office ISBN 90 12 08099.

Annex

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General Literature

There is an extensive literature available about methods for estimating emissions and establishing emission inventories, in particular for air emissions. The U.S. Environmental Protection Agency (USEPA) has produced a great number of very relevant publications to assist the estimation of pollutant emissions. However, in general literature about emission inventories integrated over the different environmental compartments (multimedia), as is the case of the PRTR, is scarce. The following publications could be useful:

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UNITAR

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