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Estimating Costs for Controlling Emissions of Volatile Organic Compounds (VOC) from Stationary Sources in Europe

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1 Introduction

Integrated assessment models are tools to combine information and databases on the economic, physical and environmental aspects relevant for the design of strategies for reducing the impacts of air pollution. The **R**egional **A**ir **P**ollution **IN**formation and **S**imulation (RAINS) model developed at the International Institute for Applied Systems Analysis (IIASA, Laxenburg, Austria) provides a consistent framework for the analysis of emission reduction strategies, focusing at acidification, eutrophication and tropospheric ozone. RAINS comprises modules for emission generation (with databases on current and future economic activities, energy consumption levels, animal livestock numbers, fuel characteristics, etc.), for emission control options and costs, for atmospheric dispersion of pollutants and for environmental sensitivities (i.e., databases on critical loads). In order to create a consistent and comprehensive picture of the options for simultaneously addressing the three environmental problems (acidification, eutrophication and tropospheric ozone), the model considers emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_x), ammonia (NH_3) and the volatile organic compounds (VOC). A schematic diagram of the RAINS model is displayed in Figure 1.

This paper provides documentation of the RAINS module that describes emissions, control potential and control costs of volatile organic compounds (VOC) from stationary sources. Section 2 introduces the sectoral structure of the VOC emission module for stationary and mobile sources; after this a brief characteristic of the various control measures applicable to the individual emission sources is provided. Section 4 reviews the methodology for cost calculation for stationary sources.

1.1 The Objectives of an Emission Control Cost Module within the Framework of an Integrated Assessment Model

A central objective of integrated assessment models is the assistance in the cost-effective allocation of emission reduction measures across different pollutants, different countries and different economic sectors. Obviously, this task requires consistent information about the costs of emission control at the individual sources, and it is the central objective of this cost module to provide such information.

The optimal cross-country allocation of emission control measures is crucially influenced by differences in emission control costs for the individual emission sources. It is therefore of utmost importance to systematically identify the factors leading to differences in emission control costs among countries, economic sectors and pollutants. Such differences are usually caused, inter alia, by variations in the composition of the various emission sources, the state of technological development and the extent to which emission control measures are already applied.

In order to systematically capture these differences across Europe, a methodology has been developed which estimates the emission control costs of standard technologies under the specific conditions characteristic for the various European countries. Based on the basic assumption of the general availability of control technologies with equal technical properties and costs, a number of country-specific circumstances (level of technological advancement, installation size distribution, labor costs, etc.) are used to estimate the costs for the actual operation of pollution control equipment.

The results of this economic evaluation of the available VOC control options will not predict costs for specific plants in individual countries, but will enable a general comparative analysis of different pollution control costs for different countries, source categories and pollutants.

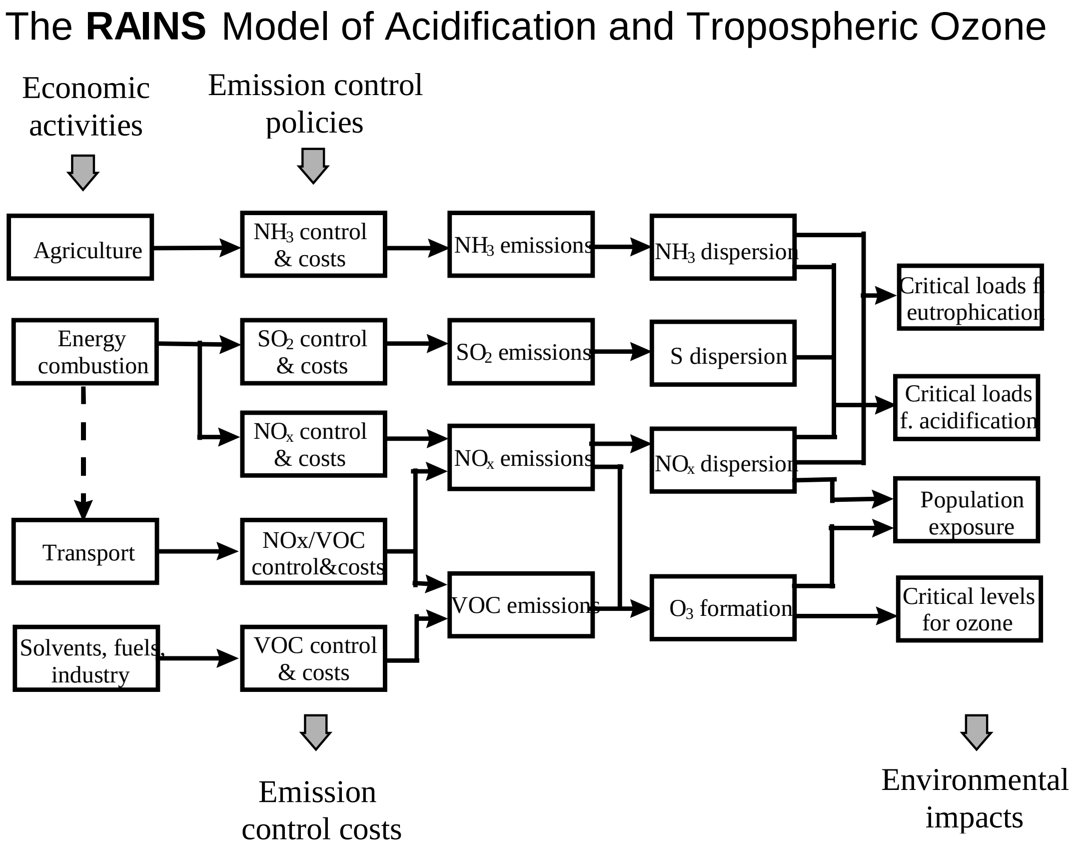

Figure 1: Schematic diagram of RAINS model

2 The Structure of the VOC Module

This section reviews three aspects important for modeling future costs for controlling VOC emissions across Europe. A methodological key question relates to the appropriate level of aggregation at which the international analysis is carried out best. After presenting the main criteria for determining the appropriate level, Section 2.1 introduces the sectoral aggregation level selected for the RAINS VOC module. Having decided about the aggregation level, the next question arises about the selection of meaningful activity levels, the availability of representative emission factors (Section 2.2), and the possibilities for forecasting their future development (Section 2.3).

2.1 Aggregation of Emission Sources

Emissions of VOC are released from a large variety of sources with significant technical and economic differences. Conventional emission inventory systems, such as the CORINAIR inventory of the European Environmental Agency, distinguish more than 300 different processes causing VOC emissions.

In the ideal case, the assessment of the potential and costs for reducing emissions should be carried out at the very detailed process level. In reality, however, the necessity to assess abatement costs for all countries in Europe as well as the focus on emission levels in 10 to 20 years from now restrict the level of detail which can be maintained. While technical details can be best reflected for individual (reference) processes, the accuracy of estimates on an aggregated national level for future years will be seriously hampered by a general lack of reliable projections of many of these process-related parameters (such as future activity rates, autonomous technological progress, etc.). For an integrated assessment model focusing on the pan-European scale it is therefore imperative to aim at a reasonable balance between the level of technical detail and the availability of meaningful data describing the future development and to restrict itself to a manageable number of sources categories and abatement options.

For the RAINS VOC module, an attempt was made to aggregate the emission producing processes into a reasonable number of groups with similar technical and economic properties. Considering the intended purposes of integrated assessment, the major criteria for an aggregation were:

- Importance of the emission source. It was decided to target source categories with a contribution of at least 0.5 to 2 percent to the total anthropogenic emissions in a particular country.
- Possibility to define uniform activity rates and emission factors.
- Possibility of constructing plausible forecasts of future activity levels. Since, in the RAINS model, the emphasis of the cost estimates is on future years, it is crucial that reasonable projections of the activity rates could be constructed or derived.
- Availability and applicability of ‘similar’ control technologies.

- Availability of relevant data. Finally, the successful implementation of the module will only be possible if the required data are available. As far as possible, emission related data should be compatible with the CORINAIR emission inventory.

Table 1 and Table 2 present the source structure selected for the RAINS VOC module and the contribution of the source categories to the total European NMVOC emissions in 1990. This statistic is derived from the CORINAR'90 emission inventory. Note that natural sources as well as emissions from *Cultures with and without fertilizers (CORINAIR'90 SNAP[1] codes 100100 and 100200)* are excluded. The RAINS source structure distinguishes 10 emission categories for mobile and 34 groups for stationary sources.

The results presented in Table 1 are derived from the CORINAIR'90 inventory. The 'secondary sectors' given in this table do not show all emission categories considered in the RAINS model, however. Since one of the objectives of RAINS is to evaluate costs of emission control, the model sectoral structure has been adjusted accordingly, for example, by distinguishing between four and two-stroke gasoline engines as well as between medium and large size vessels for shipping. A detailed description of the transport related sectors in the model is presented in Cofala and Syri, 1998.

Similarly, Table 2 presents the aggregation scheme for stationary sources with the European emissions derived from CORINAIR'90.Although not all European countries reported data to the CORINAIR system (28 in total), the conclusions given below about the importance of major emission categories will not change.

Table 1: Sectors included in RAINS VOC module[2] for mobile sources and their contributions to total European NMVOC emissions

Sectors		**Emissions**	**Share in**	**Countries**
Primary	***Secondary***	**[kt/year]**	**total [%]**	**reporting**
Road Transport	Light duty trucks	382	2.3	26
	Passenger cars	3466	20.8	27
	Gasoline evaporation	1550	9.3	25
	Trucks and busses	665	4.0	27
	Motorcycles and mopeds	701	4.2	26
Other Transport	Air traffic (LTO[3])	71	0.4	23
	Off-road vehicles	419	2.5	20
	Railways	33	0.2	23
	Ships	155	0.9	20

In 1990, the main contributions to European VOC emissions came from transport (>40 percent) and solvent use (~30 percent). Looking at the types of activities, about 50 percent of European VOC emissions were related to the production, distribution and use

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1 **S**elected **N**omenclature for **A**ir **P**ollution (SNAP).

2 This table is derived from CORINAIR'90 database. Complete relation between secondary sectors distinguished in this table and CORINAIR'90 SNAP Code is given in Annex 1.

3 Landing and Take-Off (LTO)

of liquid fuels. Another 30 percent were caused by the use of solvents in various sectors, mainly surface coating (~11 percent) and other use in industry (~14 percent). The remaining 15 percent originated from stationary combustion, chemical industry and from miscellaneous sources.

Table 2: Sectors distinguished in RAINS VOC module[4] for stationary sources and their contributions to total European NMVOC emissions

Sectors		**Emissions[5] [kt/year]**	**Share in total [%]**	**Countries reporting**
Primary	***Secondary***			
Solvent Use	Dry cleaning	125	0.7	22
	Metal degreasing	400	2.4	20
	Treatment of vehicles	74	0.4	10
	Domestic solvent use (excluding paint)	492	2.9	12
	Architectural painting	*500*	3.0	20
	Domestic use of paints	*250*	1.5	20
	Manufacture of automobiles	*200*	1.2	19
	Other industrial use of paints and *Vehicle refinishing*	*973*	5.8	25
	Products incorporating solvents	*267*	1.6	24
	Products not incorporating solvents	*291*	1.7	26
	Pharmaceutical industry	115	0.7	16
	Printing industry[6]	278	1.7	17
	Application of glues & adhesives in industry	187	1.1	16
	Preservation of wood	136	0.8	10
	Other industrial use of solvents	632	3.8	20
Chemical Industry	Inorganic chemical industry	117	0.7	10
	Organic chemical industry	*400*	2.4	21
Refineries	Refineries – processes	155	0.9	22
Fuel Extraction and Distribution	Gaseous fuels: extraction, loading, distribution	258	1.5	16
	Liquid fuels: extraction, loading, distribution	519	3.1	16
Gasoline Distribution	Service stations	403	2.4	24
	Refineries (storage), transport, depots	288	1.7	22
Stationary Combustion	Public power, co-generation, district heating	55	0.3	27
	Industrial combustion	154	0.9	27
	Commercial and residential combustion	989	5.9	26
Miscellaneous	Stubble burning & other agricult. waste	435	2.6	13
	Food and drink industry	279	1.7	23
	Other industrial sources	176	1.1	25
	Waste treatment and disposal	105	0.6	23

[4] This table is derived from CORINAIR'90 database. The complete relation between secondary sectors distinguished in this table and the CORINAIR'90 SNAP code is given in Annex 1.

[5] Numbers printed in *italic* indicate that the estimates were derived from CORINAIR categories with some adjustments by the authors, e.g., splitting some of the emissions reported under SNAP level 2.

[6] Includes separate categories for packaging, publishing, offset, and screen printing.

2.2 Activity Units and Emission Factors

The basic concept of the RAINS emission calculation is to estimate emissions, for each of the source categories distinguished in the model, as a product of the activity rate, the (unabated) emission factor and the removal efficiency of applied emission control devices (taking into account the penetration of emission controls).

$$E(VOC)_k = \sum_l \sum_m \sum_n A_{k,l,m} \times ef_{k,l,m} \times (1 - \eta_{l,m,n} \times \alpha_{k,l,m,n}) \times X_{k,l,m,n} \qquad (1)$$

where

k,l,m,n	country/region, sector, fuel, abatement technology;
E(VOC)	emissions of NMVOC;
A	activity rate;
ef	(hypothetical) unabated emission factor ;
η	removal efficiency;
α	maximum application rate (further referred to as applicability);
X	actual application rate of control technology *n*.

It is important to carefully define appropriate activity units that are detailed enough to provide meaningful surrogate indicators for the actual operations of a variety of different technical processes, and aggregated enough to allow a meaningful projection of their future development with a reasonable set of general assumptions. As a general approach, RAINS uses country-specific emission factors derived from the information provided in the CORINAIR'90 inventory and in other national studies and emission inventories (e.g., Passant, 1993; SHI, 1994; McGettigan, 1993). Only in cases where no country-specific information is available, default emission factors derived from several international studies are used (e.g., EEA, 1996; EC, 1994; BUWAL, 1995; IFARE, 1998; EPA, 1994; etc.).

Equation (1) represents the general formula for calculating emissions. However, as explained later in the text, the RAINS sectors often contain a number of VOC emitting processes. It is often the case that for such aggregated sectors (*l*) some emission control options (*n)* are not necessarily applicable to all processes (emission sources) that are represented by the activity *(A)*.

Note that in the calculation routine, for a given fraction of activity *(A)*, the control options *(n)* are exclusive, i.e., that only one of the available control options can be applied at the same time. If in a given sector several emission control options can be applied simultaneously, then in the model a new control option is defined which represents the combined application of several single control options. In such a case, removal efficiency (η) and applicability (α) for this new option are determined reflecting the sector- and technology specific interactions of the single options.

2.2.1 Activities Related to the Use of Fossil Fuels

For some of the RAINS sectors it seems plausible to relate the activity levels to the consumption of particular fuels, for which future projections are available as part of the energy scenarios used as exogenous input to the model. This applies to stationary combustion, refineries, gasoline distribution, gasoline evaporation from cars, and the extraction and loading of liquid and gaseous fuels (see Table 3).

Table 3: Activity units and default (unabated) emission factors for fuel-related source categories

Sector	**Activity unit**		**Default emission factor**	
		Unit		Unit
Stationary combustion[7]	Use of hard and brown coal			
	- existing power plants, industry	PJ	0.0150	kt/PJ
	- new power plants	PJ	0.0015	kt/PJ
	- residential	PJ	0.2000	kt/PJ
	Use of heavy fuel			
	- existing power plants, industry	PJ	0.005	kt/PJ
	- new power plants	PJ	0.003	kt/PJ
	Use of light fuel oil	PJ	0.003	kt/PJ
	Use of gasoline	PJ	0.002	kt/PJ
	Use of natural gas			
	- power plants, industry	PJ	0.004	kt/PJ
	- residential	PJ	0.005	kt/PJ
	Use of biomass			
	- power plants, industry	PJ	0.048	kt/PJ
	- residential	PJ	0.600	kt/PJ
Refineries - process	Input of crude oil	Mt	2.34	kt/Mt
Gasoline evaporation	Use of gasoline	PJ	0.1 - 0.5[8]	kt/PJ
Service stations	Use of gasoline	PJ	0.0643	kt/PJ
Transport and depots	Use of gasoline	PJ	0.07	kt/PJ
	Use of diesel	PJ	0.0012	kt/PJ
Air traffic (LTO)	Emissions of NMVOC	kt	1.0	kt/kt
2-stroke gasoline engines	Use of gasoline (mopeds)	PJ	8.0	kt/PJ
	Use of gasoline (off-road)	PJ	10.0	kt/PJ
Shipping	Use of diesel and residual oil	PJ	0.06	kt/PJ
Extraction, loading and distribution of fossil fuels	Emissions of NMVOC	kt	1.0	kt/kt

For reasons of simplicity, the activity rates for 'extraction, loading and distribution of fossil fuels' relate to the emissions reported in the CORINAIR'90 inventory, assuming an uncontrolled situation. A possible refinement would be to distinguish individual emission generating activities (e.g., off-shore production of oil and/or natural gas, etc.) separately, if this turns out to be of crucial importance for the overall calculation results.

[7] For the majority of countries country-specific data was available.

[8] Values are determined based on the climatic zone, the shares of carburetor and direct injection engines as well as assumptions about driving habits.

2.2.2 Solvent Use

Solvents are emitted by a large variety of activities, including the production and use of paints, cosmetics, rubber, chemicals, etc., and cleaning in industry and households. Since it is difficult to derive, at least for some of these specific activities, reliable projections for their future development, a set of surrogate indicators have been employed. Such surrogate activity rates include the use of solvents or of solvent-containing products, the amount of manufactured goods, the area coated, other process inputs, value added in a specific industry, or even simply the population in a country (see Table 4 for details).

Nearly half of the NMVOC emissions from solvent use arises from the consumption of paint in industry, the commercial and domestic sector (>14 percent of total emissions).

For the architectural and domestic use of paint, many emission inventories use emission factors related to per capita or per kilogram paint applied (assuming a certain content of solvents), depending on the available information. RAINS uses paint consumption as the activity unit for these activities as well as for vehicle refinishing and other industrial painting. The corresponding emission factors assume a certain (country-specific) average solvent content of the paint and a particular application method (CORINAIR'90 database; EEA, 1996; Hein *et al.*, 1994; Passant, 1993; etc.).

For the use of paint in automobile production the number of vehicles produced is used as activity rate. The emission factor is based on typical values of uncontrolled application taking into account country-specific production profiles and requirements for emission controls (EEA, 1996; Adler, 1993; Hein *et al.*, 1994; IFARE, 1998; CITEPA, 1994).

For describing the activity levels for various industrial sectors (metal degreasing, pharmaceuticals production, preservation of wood) RAINS uses the consumption of solvents of these processes. Alternatively, for wood preservation, the volume of wood treated can be used. Statistics on industrial roundwood are available from FAO (FAO, 1997) but if country-specific information about the share of wood treated is not available, appropriate assumptions need to be made. For all printing categories recognized in the model (packaging, publishing, offset, screen printing) consumption of ink is used as activity level.

Another important source of NMVOC emissions is the domestic use of solvents (other than paints). This category comprises a wide range of articles used in households, e.g., household and personal care products, adhesives and glues as well as automotive maintenance products. Due to the absence of reliable detailed information, RAINS applies similar to many other emission inventories the simple approach based on per-capita emission factors. These emission factors were derived from information contained in the CORINAIR'90 inventory, the Emission Inventory Guidebook (EEA, 1996), Passant and Vincent (1998) as well as Umweltministerium Baden-Württemberg (1993).

Lack of detailed information leads also to the use of simple per capita relations to estimate the emissions from the treatment of vehicles (de-waxing and underseal treatment). Alternatively, data on new and total vehicle registrations can be used assuming certain practices, i.e., a percentage of cars that undergo underseal treatment, etc. (compare Table 4).

Table 4: Activity units and default (unabated) emission factors for solvent use

Sector	Activity	Unit	Default emission factor	Unit
Paint application				
Architectural	Paint used	kt	0.30	kt/kt
Domestic	Paint used	kt	0.41	kt/kt
Vehicle refinishing	Paint used	kt	0.85/0.46 *	kt/kt
Automobile manufacturing	Vehicles manufactured	kveh	No default value[9]	kt/kveh
Other industrial	Paint used	kt	0.73	kt/kt
Degreasing	Solvent used	kt	0.90/0.72 *	kt/kt
Printing				
Packaging	Ink used	kt	2.1/0.42 *	kt/kt
Publishing	Ink used	kt	1.5/0.18 *	kt/kt
Offset printing	Ink used	kt	0.72/0.45 *	kt/kt
Screen printing	Ink used	kt	0.40/0.36 *	kt/kt
Preservation of wood	Solvent used	kt	0.73/0.44 *	kt/kt
	Wood treated	m^3	5 - 20[10]	kg/m^3
Pharmaceuticals	Solvent used	kt	0.15	kt/kt
Domestic use of solvents	Population	mln	2.0/1.0[11]	kg/cap
Vehicle treatment	Population	mln	No default value[12]	kg/cap
Dry cleaning	Textiles cleaned	kt	0.125/0.05 *	kt/kt
Products incorporating solvents (e.g., paint, inks)	Production	kt	0.025[13]	kt/kt
Products not incorporating solvents (e.g., rubber)	Emission of NMVOC	kt	1.0	kt/kt
Application of glues and adhesives in industry	Emission of NMVOC	kt	1.0	kt/kt
Other industrial use of	Emission of NMVOC	kt	1.0	kt/kt

(*) - Value for existing and new installations, respectively.

Although some national inventories calculate emissions from dry-cleaning on the basis of per capita emission factors, the significant differences in lifestyles over Europe suggest the use of the amount of textiles cleaned per year as the general explanatory variable (activity rate). Thereby, alternative scenarios could include assumptions about

9 Depends on the proportion of passenger cars and trucks manufactured in a given country/region (typically, the value varies between 10-30 kg/vehicle).

10 Depends on the assumption about the proportion of wood preserved with creosote, organic solvents and water-based solvents as well as on the preservation method used.

11 If no country-specific information available, value for Western and Eastern Europe, respectively.

12 Per-capita factors can be estimated using information about car registration (new and total) and assuming a percentage of cars undergoing underseal treatment (emission factor 2.7 kg/vehicle) and dewaxing (default emission factor 3 kg/vehicle).

13 If information on production of paint, inks, etc. is available then this factor can be adjusted to take into account different shares of products (typically the emission factor will vary between 15 and 40 kg/t of product).

changes in lifestyles over time in different European countries. As far as possible, statistical data about the amount of textiles cleaned have been derived from the CORINAIR'90 inventory. For countries where this information was not available assumptions about the per-capita demand for textiles cleaned were made.

For calculating VOC emissions from the production of paint and glues the amount of manufactured product is used as the explanatory variable.

For other industrial activities (production of rubber and inks, application of glues and adhesives, solvent use in the textile-, leather- and other industries) the data availability shows great differences over the various European countries and the relative contribution of the individual activities is often unknown. Although in some instances more detailed information is available, it was decided, in the interest of maintaining international consistency, to simply use the (country-specific) average emission factors reported for these activities for 1990.

2.2.3 Organic and Inorganic Chemical Industry

The manufacturing, storage and handling of more than 20 products in the organic chemical industry (as recognized in CORINAIR'90 inventory, see Annex 1 for details) contributes about 2.4 percent to total European NMVOC emissions. Another 0.7 percent arise from production processes in inorganic chemical industry. In the context of a pan-European analysis it does not seem worthwhile to distinguish all the individual processes, but to treat them on an aggregated level instead. A problem arises, however, when determining the appropriate emission factor related to the aggregated activity level for these processes. The relative shares of these activities vary greatly over Europe and the identification of a single representative activity seems problematic. It was therefore decided to represent the differences by using emissions, reported for 1990, as the activity rate and let them change over time with different economic development. Additionally, for organic chemical industry, storage of products is recognized as a separate category, since the control options are distinctly different from the ones applied for the process part.

Table 5: Activity units and default emission factors for the chemical industry

Sector	**Activity**		**Default emission factor**	
		Unit		Unit
Organic chemical industry	Emissions of NMVOC	kt	1.0	kt/kt
Inorganic chemical industry	Emissions of NMVOC	kt	1.0	kt/kt

2.2.4 Miscellaneous Sources

The source categories discussed in previous sections leave out a number of rather different activities responsible for more than one million tons of NMVOC emissions in 1990 in the whole of Europe. They comprise a wide spectrum of economic activities ranging from agriculture and food industry to waste treatment, road paving with asphalt, and heavy industry (coke oven, iron and steel, pulp and paper, etc.). At this stage RAINS uses the 1990 emissions of NMVOC as explanatory variable for most of the sectors.

The only exception is the food and drink industry. In most countries, the majority of emissions from this sector originate from bread manufacture; only in few cases spirits production plays an important role. Therefore, it seems both plausible and feasible to use per capita emission factors with population as the activity levels. The default emission factor presented in Table 6 refers to the 'typical' situation, where about 80 percent of the emissions are caused by bread manufacture.

Table 6: Activity units and default emission factors for miscellaneous sources

Sector	**Activity**		**Default emission factor**	
		Unit		Unit
Food and drink industry	Population	mln	0.3	kg/cap
Stubble burning	Emissions of NMVOC	kt	1.0	kt/kt
Other industrial sources	Emissions of NMVOC	kt	1.0	kt/kt
Waste treatment and disposal	Emissions of NMVOC	kt	1.0	kt/kt

2.3 Forecast of Activity Levels

A central objective of the RAINS model is the estimate of emission control costs with a time perspective of 15 to 20 years into the future. Future costs in a country will be obviously determined by the costs for applying certain emission control technologies or reduction measures. Another, often more important, factor is the future rate of emission generating activities in the country, such as industrial production, fuel consumption or transport services. RAINS captures this aspect by modifying the present activity levels according to exogeneously provided projections, e.g., for the year 2010. As a matter of fact, reliable and consistent projections of future activity rates at the process level are hardly available; most economic long-term forecasts restrict themselves to a rather aggregated level of economic activities and do rarely specify even the development of the main economic sectors. Therefore, a key question for modelling future abatement costs is which generally available long-term forecasts (such as energy projections, sectoral GDP development, etc.) could be used to derive the temporal changes of the activity rates employed for the emission calculation.

At present, RAINS applies four concepts for constructing forecasts of sectoral activity rates:

- The change of the activity rates for processing, distribution and combustion of fossil fuels is linked to changes in fuel consumption provided by the energy scenario input to RAINS. Internal consistency with the energy scenario used for calculating SO_2 and NO_x emissions is maintained.
- Some other activity rates (dry cleaning, use of solvents in households, vehicle treatment, food and drink industry) are assumed proportional to population development (possibly taking also into account changes in GDP per capita which affects lifestyles).
- The temporal development of a number of industrial activities (e.g., degreasing, paint use, solvent use in chemical industry, printing, other industrial solvent use) is related to changes in the sectoral gross domestic product (often supplied with the energy scenario). In many cases, statistics suggest that these activities grow slower than the

value-added. To reflect this trend, sector-specific elasticities derived from statistics have been applied.

- In absence of more information the activity rates for less important emission sectors are kept constant. This was typically done (i) for sectors where current emissions estimates are very uncertain (e.g., agriculture, waste treatment), (ii) where it is difficult to identify meaningful relations with other economic activities, and (iii) for sectors where the increase in activity rates are expected to be offset by emission reductions induced by autonomous technical improvements.

3 Emission Control Options

There is ample national and international literature documenting the application of available options for reducing emissions of VOC. Comprehensive summaries can be found in Jourdan and Rentz, 1994; EPA, 1994; OECD,1990; EEC, 1990; Allemand *et al.*, 1990; ERM, 1996; Bouscaren *et al.*, 1990; Breihofer *et al.*, 1991; Hein *et al.*, 1994; Rentz *et al.*, 1993; KWS 2000, 1996; CONCAWE, 1987-1993, IFARE, 1998).

Commonly employed methods of reducing VOC emissions from stationary sources can be grouped into four basic classes:

- **Basic emission management techniques,** i.e., modification of the production process, and/or improvement of the management practices (good housekeeping, leak monitoring and repair programs, etc.).
- **Reduction of storage losses** from tanks including internal floating covers and secondary seals.
- **Solvent substitution** (use of low solvent or solvent free products).
- **Add-on techniques**, such as thermal or catalytic incineration, adsorption, absorption, condensation/ refrigeration, biooxidation, and vapor recovery systems.

It is important to realize, for designing a VOC control strategy, that the choice of the appropriate measure will depend not only on costs or the availability of a certain technology, but also on the applicability and desirability. Unfortunately, it is difficult to accurately estimate the application potential (the 'applicability'), particularly since it depends on a number of site-specific characteristics. There are a number of reasons for significant differences in the application potential of a given emission control option:

- In many cases the applicability will depend more on the characteristics of a specific point of emissions (e.g., drying oven) rather than on the source category (e.g., automobile manufacturing/ surface coating).
- Some sectors (e.g., refineries) include several processes that release VOC emissions and the applicability of a selected technology depends on the specific process.
- The size distribution of the installations in a given source category.
- Reformulated products may not be available for all applications within a given source category or substitutes will not be accepted due to the resulting decrease in the quality of finish.
- Variable parameters of emission streams, e.g., too low or too high concentrations of VOC in the stream gas or too low or too high flow rates limiting the application of particular technique.
- Mixture of solvents used in the process, making it impossible to apply some of the add-on technologies.

Another important factor concerning the applicability of a certain measure is the distinction between existing and new sources, i.e., whether an emission control measure will be retrofitted to an existing installation or integrated in the course of constructing a new (production) unit. Since the control of VOC emissions is currently a subject of general concern in Europe, it is assumed that some of the 'integrated' control options (especially process changes and substitution of raw materials) will become standard in the near future and will slowly replace existing production processes with higher VOC emissions. It is further assumed that some of these 'integrated' control techniques, which form part of the new production technology, can be introduced at no extra cost. As a practical example, open circuit machines are currently used in many countries for dry cleaning. These machines, which are considered in RAINS as the 'no-control' reference case, are now gradually replaced by closed circuit machines with internal refrigerated condensers with lower VOC emissions. RAINS assumes that this replacement occurs at no extra costs attributable to VOC reduction.

Furthermore, the already installed control measures have an influence on the applicability of the remaining options. RAINS takes this into account by considering the 'initial controls', i.e., the control measures implemented in the base year.

3.1 Gasoline Evaporation

CAR_EVAP

Evaporative emissions of NMVOC from gasoline powered vehicles *(CORINAIR'90 and '94 SNAP code 070600)* accounted for more than 20 percent (~3.5 million tons) of total anthropogenic emissions in Europe in 1990. It should be noted that refueling losses are not included in this category but are estimated as part of the emissions from gasoline stations (see Section 3.4.3.2). The three main sources of evaporative emissions from vehicles are:

- diurnal emissions - result from the vapor expansion inside the gasoline tank that is associated with the daily variation in ambient temperature,
- hot soak emissions - occur when a hot engine is turned off and the heat from the engine and exhaust system raises the temperature of the fuel system, and
- running losses - during vehicle operation, high ambient temperature and heat from the exhaust system will contribute to the generation of vapor in the gasoline tank.

The magnitude of emissions from these sources will be affected by the volatility of the gasoline, the ambient temperature, temperature changes, vehicle design characteristic and driving habits. More details on the characteristics of evaporative emissions can be found in EEA (1996).

Control options include small and large on-board carbon canisters, which adsorb gasoline vapors and desorb them to the engine under appropriate conditions. Also, use of lower volatility gasoline results in reduction of emissions. Currently RAINS includes **small carbon canisters** (SCC) as a control option with an efficiency of 85 percent. The EU Directive 91/441/EEC requires the installation of carbon canisters in all new gasoline passenger car models since 1993.

3.2 Solvent Use

Solvents are used in a variety of industrial processes. Since solvents are often also contained in the final product, they are not only emitted at the place of manufacturing, but also released later during use (application). In 1990, solvent use was the largest source of NMVOC emissions from stationary sources contributing about 50 percent or nearly 30 percent of total anthropogenic emissions in Europe in 1990.

The methods of reducing VOC emissions resulting from solvent use can be grouped into three broad categories:

- Process modification including the improvement of management practices. Examples are reducing or combining two steps of the production process, altering the temperature of a certain process, regular maintenance programs to identify and prevent leaks, etc.;
- Solvent substitution aiming at reduced solvent use (use of low-solvent or solvent-free products);
- Add-on technologies including thermal or catalytic oxidation, carbon adsorption, absorption, refrigeration/condensation and biooxidiation.

For non-industrial use of solvents as well as for ’non-enclosed’ industrial processes solvent substitution or process modification are viable control options. Add-on technologies are appropriate for ‘enclosed’ operations where solvents can be captured. It is believed that there is a large potential to reduce NMVOC emissions applying the first category of options.

3.2.1 Surface Cleaning

Surface cleaning, i.e., dry cleaning *(CORINAIR’90 and ‘94 SNAP code 060202)* and degreasing *(CORINAIR’90 and ‘94*[14] *SNAP code 060201)*, contribute about 530 kt (~3 percent) to total anthropogenic VOC emissions. Most of the countries participating in the CORINAIR’90 exercise reported emissions from these activities.

3.2.1.1 Dry Cleaning

DRY
DRY NEW

Dry cleaning refers to any process to remove contamination from furs, leather, textiles, etc., using halogenated solvents *(EEA, 1996)*. The halogenated hydrocarbons used can be divided into two groups:

- Chlorinated hydrocarbons, including perchloroethylene (PERC), trichloroethylene and other solvents, and
- chlorofluorocarbons (CFC’s), including mostly trichlorotrifluoroethane (R113).

The most important hydrocarbons are PERC and R113, with a market share of PERC of about 90 percent. More details can be found in Jourdan and Rentz (1991).

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[14] SNAP ’94 distinguishes also two additional categories in group 0602 [Degreasing, dry cleaning and electronics], namely *Electronic components manufacturing (060203)* and *Other industrial cleaning (060204).*

In the dry cleaning process four steps can be distinguished:

- cleaning in a solvent bath,
- drying with a hot air,
- deodorisation and
- regeneration of solvents.

VOC emissions occur at all of these stages at a number of places, such as dryers, washers, solvent filtration systems, settling tanks, stills, and at the piping and ductwork associated with the installation and operation of these devices. Emissions are highly dependent on the type of process, the solvent used, and on correct operation and maintenance. For 1990, emissions from this sector are estimated in CORINAIR at about 125 kt (~0.7 percent of total VOC).

It has to be noted that emissions of CFC's (machines operating on R113) are not accounted for in CORINAIR'90. Since, for the protection of the ozone layer, R113 might be replaced in the future with PERC, the calculated NMVOC emissions may rise.

There are basically two types of machines used in the dry cleaning sector: machines with open and closed circuit. Open circuit machines may be regarded as uncontrolled technology. The closed circuit machines can be subdivided into conventional and new generation types. The conventional type has internal refrigerated condensers (IRC); the level of emissions is comparable to open machines with activated carbon adsorption (ACA), or lower. It might be possible to control the emissions from these machines even further.

In principle, conventional closed circuit machines could be treated as a control option if they replace open-circuit units; however, analysis suggests that the cost-effectiveness of such a replacement seems to be lower than that of the new generation closed-circuit machines which have the IRC and ACA units already integrated.

Based on information provided in several studies (Jourdan and Rentz, 1991; EPA, 1994; Passant, 1993; EEA, 1996; ECE, 1990 RAINS distinguishes three control options for dry cleaning:

- **Activated carbon adsorption** (ACA) and good housekeeping (HSE), applicable to existing open-circuit machines operating on halogenated solvents, assumed efficiency 60%. It is important to determine what was the proportion of emissions from open circuit machines in different countries in 1990.

- **Conventional closed-circuit machines** (CCCM) which in many countries become the "no control" technology for new installations, assumed efficiency 76 percent.

- **New generation closed circuit systems** (NCCM); an efficiency of around 90 percent has been demonstrated.

3.2.1.2 Degreasing

DEGR DEGR NEW

Solvent cleaning (degreasing) uses organic solvents to remove water-insoluble impurities (e.g., grease, fats, waxes) from metal, plastic, fiberglass, and other surfaces. Organic solvents applied for this purpose include petroleum distillates, chlorinated hydrocarbons, ketones, and alcohols. Degreasing is important in automobile manufacturing and in the production of electronics, appliances, furniture, aircraft and business (office) machines such as computers, photocopiers etc. For 1990, total European emissions (CORINAIR'90 database) from this activity were estimated at about 400 kt of NMVOC, which represents nearly 2.5 percent of total.

For degreasing, two basic types of machines (open-top and enclosed) can be distinguished. Open-top machines are more popular due to their simple and robust design. However, they have higher VOC emissions than the more capital-intensive enclosed machines. Actual emissions are strongly influenced by the design and the appropriate operation and maintenance, which is particularly important for open-top machines. More details on degreasing operations can be found in Hein, *et al.*, 1994; EPA, 1994; ECE, 1990; Heslinga, 1990.

It has to be stressed that this sector is characterized by a large variability in the size of the installations (measured by the amount of solvents used), typically with a large number of small units. This has an implication on the possibility of control in this sector.

The RAINS-VOC module distinguishes the following control options for this sector:

- **Basic emission management techniques** (BEMT). This group of measures includes good housekeeping (proper operation and maintenance), improved containment achieved by improved covers, and other primary measures like higher and refrigerated freeboards. These measures are applicable to most of the existing installations and it is assumed that they will be (autonomously) integrated in new installations. Although it has been demonstrated that the combined efficiency of such measures can reach 40 to 60 percent (EPA, 1994; ECE, 1990, Hein *et al.*, 1994), RAINS assumes an average overall efficiency of about 20 percent.

- **Substitution**, i.e., switch to water-based systems (WBS), possibly involving some modification. Elimination of solvents and replacing them by "water and soap" results in a 100 percent reduction of VOC emissions. Substitution is an option both for existing and new installations. It is difficult to precisely estimate the application potential, since it depends on a number of country-specific circumstances. Typical estimates range from 50 percent to more than 70 percent in Germany.

- **Activated carbon adsorption** (ACA) can reduce VOC emissions by up to 80 percent. It can be applied to most of the existing and new sources, particularly for medium and large installations. Some studies claim, however, that ACA is generally not an economic option (ECE, 1990).

- **Low temperature plasma process** (LTPP). This technique is already applied in some sectors and its share is expected to grow further. Typical removal efficiencies are estimated at 98 percent (IFARE, 1998) with an applicability to 70 percent of the sources.

- **Conveyorised degreasers with integrated carbon adsorption** (CD-ACA). This type of enclosed degreasers is continuously loaded and is often combined with carbon adsorption. The efficiency of 95 percent is assumed (IFARE, 1998) with an applicability of up to 90 percent.

- Furthermore, a number of combinations of the above options are also considered in the RAINS-VOC module (see Annex 2).

3.2.2 Treatment of Vehicles

VEHTR

This sector, in the RAINS-VOC module, includes two CORINAIR'90 and '94 SNAP 3 categories, i.e., *Underseal treatment of vehicles (060407)* and *Vehicle de-waxing (060409)*. Although for 1990 the overall contribution of this sector is only estimated at about 0.4 percent to total European VOC emissions, its true importance is most likely higher because only 10 countries participating in CORINAIR'90 reported emissions from these activities.

For underseal treatment, substitution with a hot melt type of coating is a viable emission control option (Adler, 1993), but it is not considered in the model at this stage due to lack of appropriate data.

For de-waxing, possible control options include cleaning with hot water/soap in combination with an installation for the separation of the water/wax mixture and, if transport conditions allow (e.g., if transported by trucks), no protective layer. Due to insufficient data, these options are not considered in RAINS yet.

3.2.3 Use of Solvents in the Domestic Sector

DOM_OS

Domestic solvent use is one of the very important sources of VOC emissions in Europe *(CORINAIR SNAP'90 and '94 code 060408)*. It includes the non-industrial use of solvent containing products (excluding paints), such as household and personal care products, adhesives and glues as well as automotive maintenance products. In the CORINAIR'90 inventory emissions from this sector amount to about 500 kt, which would be about three percent of total emissions. However, only 12 countries reported emissions from this sector to CORINAIR'90. Since there is no doubt that these products are used in all countries, real emissions could be more than twice as high, which puts this sector among the most important sources.

Options for reducing emissions from domestic solvent use include:

- A **change in the application method** (repackaging, e.g., roll-on, pump-spray, solid stick, etc.).
- **Product substitution/reformulation** (non-VOC or low VOC products). This category includes the substitution of glues by so-called 'hot melts'. Only little is known about the effectiveness of this option, so that several research programs on developing low/non-VOC products have started, which are expected to produce more information in the future. However, total emissions from the use of glues are most likely minor.
- '**Propellant insert**', i.e., replacement of some or all of the propellant with an inert gas propellant (e.g., nitrogen) in a small pressure regulating cylinder which is

inserted into the aerosol container during assembly. According to ERM (1996), 'propellant insert' seems to be a promising technology with a realistic chance for commercialization, although the figures given in the ERM study are disputed by industry and there is lack of evidence supporting the ERM numbers on achieved reduction (Passant and Vincent, 1998).

- **Directions for use**, storage and disposal (product labeling and consumer's education).

Since for some of these options only insufficient information about the costs and efficiencies is available, only two options (propellant insert (P_INS) and product reformulation (REF)) are included in the RAINS database at the moment. Even for these options the currently available data are rather uncertain, so that they are excluded from the present model calculation; these options are reserved for potential use in the future. Examples of detailed product inventories and discussion of abatement potential are presented in Passant and Vincent (1998) and in Umweltministerium Baden-Württemberg (1993).

3.2.4 Non-industrial Use of Paints

VOC emissions during paint application are caused by evaporation of the solvent used to modify the viscosity of the binder so the paint can be applied. Solvents are also used for cleaning of the equipment (brushes, spray guns, etc.). Nearly half of the total emissions from the use of paints originate from non-industrial, i.e., architectural and do-it-yourself (DIY) applications. These categories are represented in CORINAIR SNAP'90 and '94 by *Paint application: Construction and buildings (060103)* and *Domestic use (060104)*. Since the penetration of certain low solvent paints is different for private (domestic) and professional (architectural) use, RAINS treats these two categories separately.

3.2.4.1 Architectural Use of Paints

ARCH_P

In principle, there are two possibilities to control VOC emissions from the architectural use of paints, namely to modify the application technique and to use reformulated paint. Since the potential for modifying the application technique (reducing the over-spray, e.g., by using electrostatic sprays) is rather limited, only substitution is considered in RAINS at this stage.

Ongoing industrial research increases the number of available low-solvent paints and reduces the typical solvent contents to less than half of that of conventional paints. Further reductions are possible through advanced substitutes. When considering the reduction efficiencies (in the following examples relating to a conventional paint with a solvent content of 50 percent), it is also essential to take account of different coverage efficiencies of modified paint products. RAINS considers at the moment the following three options:

- **Substitution** with dispersions/emulsions (EMU) where feasible. These paints have low solvent content (about 2-3%) and are already widely used for decorative painting (available since the early 1970s) but have limited applicability to metal surfaces due to poor protective capability for metal substrates.

- **Substitution** with water-based paints (WB) other than dispersion paints. Water based paints are applied with conventional techniques and have several health, safety and environmental advantages over the organic solvent paints. There are, however, a number of problems associated with their application in the construction and building sector and in industrial applications (Section 3.2.5.3). A typical reduction efficiency of 70 to 80 percent is assumed in RAINS.
- **Substitution** with high solids paints (HS). Until now, such paints have not been widely applied in this sector due to limitations resulting from necessary application method, their toxicity, flammability, the extended drying time, etc. Reduction efficiencies between 40 to 60 percent are reported.

For estimating the emission reduction potential it is essential to assess the specific applicability in a given country, taking into account socio-economic factors, current practices (shares of dispersion as well as water based paints used), and the policies already in place. Unfortunately, only insufficient information is available on these aspects in many European countries.

3.2.4.2 Domestic Use of Paints

DOM_P

Since most do-it-yourself (DIY) applications rely on brushing and rolling, some of the professional application techniques such as spray guns are not considered as realistic options for private use. Therefore, **substitution** of conventional paints with water-based (WB), high solids (HS) and dispersions/emulsions (EMU) paints is considered as the most viable control option. The potential for such substitutions depends on the current situation, i.e., on the current market share of dispersion and water based paints, and on country-specific parameters like traditional construction materials, climate and policies already in place. Removal efficiencies are equal to those of professional paint applications (Section 3.2.4.1), but applicabilities are different for domestic use.

3.2.5 Industrial Use of Paints

Important industrial activities involving significant paint use are automobile production, construction of ships, manufacture of metal and plastic articles, wood coating, coil coating, and vehicle refinishing. In 1990 about 1.2 million tons of NMVOC were accounted from these sources, constituting 6.8 percent of total European emissions. The importance of this sector for VOC control strategies is further enhanced by its large potential for reducing these emissions.

3.2.5.1 Automobile Production

AUTO_P
AUTO_P_NEW

This source category includes the coating of vehicle bodies when they are produced *(CORINAIR SNAP'90 and '94 code 060101)*. As a multi-step operation, up to 80 percent of VOC emissions occur during the application and curing of prime coat, guide coat and topcoat (EEA, 1996; Hein *et al.*, 1994). Emissions are strongly influenced by the VOC and volume solids content of the coating, the area coated per vehicle, and the transfer efficiency.

For every country where automobile production is relevant, RAINS uses a country-specific emission factor taking into account the specific production structure and the already applied control measures.

In principle, three types of measures can be undertaken to reduce emissions from car body painting. They include substitution of the coating (by water based, high solids or powder coating), modification of the process (spraying, oven, air supply system) and installation of add-on abatement equipment. Solvent management plans (SMP) can result in VOC reductions ranging from few to several percent, depending on the plant. At this stage three options are recognized in the RAINS-VOC module:

- **Process modification and coating substitution** (PRM+SUB). Process modifications leading to optimized solvent management and improved application efficiency can be applied to spraying, ovens, and to air supply systems. Coating substitution includes the use of water-based primer and topcoat, and for special parts (fuel tanks and shock absorbers) powder paints. A 70 percent emission reduction efficiency is assumed. This option is fully applicable at existing plants (100% of non-controlled plants); new plants are assumed to apply this option by default at no extra costs.
- **Add-on abatement techniques** (A_INC) such as adsorption and incineration, with removal efficiencies of up to 95 percent. In practice, however, add-on techniques are only applicable to processes responsible for about 25 to 30 percent of VOC emissions in the sector.
- Furthermore, RAINS considers for existing plants a **combination** of the measures mentioned above (PRM+SUB+A_INC). Taking into account the limited technical applicability of add-on options, the overall efficiency is estimated at about 80 percent.

3.2.5.2 Vehicle Refinishing

VEHR_P
VEHR P NEW

It is estimated that in 1990 nearly 300 kt or three percent of total NMVOC were caused by vehicle refinishing, i.e., car-repair workshops where either whole or parts of vehicles (cars, trucks, etc.) are re-painted.

Since in the CORINAIR'90 this category is included in industrial painting, for many countries disaggregated information is not available. The CORINAIR SNAP'94 nomenclature recognizes vehicle refinishing as a separate category *(060102)*. The main reason for distinguishing this sector from other industrial painting is the fact that it has a uniform application method (spraying), and that costs and efficiencies of the control options are distinctively different from the other industrial paint applications.

Emissions can be reduced by modifying the application method, good housekeeping, other primary measures and substitution (e.g., IFARE, 1998; Hein *et al.*, 1994). RAINS considers the following control options:

- **Good housekeeping and other primary measures** (HAMP). This option includes the use of high volume low pressure spray guns (HVLP), solvent management plan, good housekeeping and enclosed gunwash. HVLP typically results in a 20 percent lower paint consumption. Also other measures lead to paint savings and result in lower emissions from the cleaning solvents. The overall efficiency is estimated at about 24 percent. Expert judgement suggests that this option is applicable to most of the car repairing workshops.

- In addition, two **combinations** of the previous option (HAMP) with substitution by water-based and high solids paints are considered. The first one (HAMP+SUB1) assumes that 50 percent of paint will be substituted by 25 % of WB and 25 % of HS paints, resulting in an overall efficiency of around 45 percent. The second combination (HAMP+SUB2) considers full substitution with 40 % HS and 60 % WB paint with an estimated overall efficiency of about 72 percent.

It is also assumed that HAMP+SUB1 is standard for new workshops.

3.2.5.3 Other Industrial Use of Paints

IND_P

In 1990, about 700 kt, i.e., about 35 percent of the VOC emissions from paint originated from the ship building industry, manufacture of plastic and metal articles, wood products industry (EEA, 1996). Since the CORINAIR'90 inventory did not distinguish between these industrial activities *(SNAP'90 code 060102)*[15] and since there is only limited information from other sources, at this stage RAINS aggregates them into one sector. Consequently, the choice of control options that are considered in RAINS had to compromise and, to a certain extent, ignore some of the characteristic differences of the individual sources (compare ERM, 1996: EEC, 1990; EEA, 1996; Hein *et al*., 1994; IFARE, 1998).

VOC emissions from other industrial paint use can be reduced by primary measures, substitution with water-based, high solids or powder paints, radiation curing, and with end-of-pipe measures. Technologically, the focus was put on primary measures and the use of high solids and waterborne systems, while less attention was given to powder paints and radiation cure systems. The applicability and acceptance of the substitute coatings is still hampered by some known problems related to

- the application method, extended drying times, sticky overspray, property losses, flammability, toxicity - for high solids;
- substrate sensitivity (WB paints are less tolerant to surface contamination), application conditions, drying time, quality, environmental issues (e.g., water pollution) - for waterborne systems;
- curing temperature, film thickness, quality - for powder coatings.

Also radiation cure systems are not trouble free; known problems include low durability and resistance to water and sunlight, health and safety issues, high material and equipment costs as well as restriction of application to flat work and thin coatings.

[15] SNAP'94 introduces separate categories for coil coating *(060105)*, boat building *(060106)*, wood *(060107)*, and other industrial paint application *(060108).*

RAINS considers the following groups of control options:

- A package of primary measures described as **good housekeeping and other primary measures** (HAM). This group includes good housekeeping, solvent management plans and the modification of spray application techniques (high volume low pressure spray guns – HVLP) to improve the transfer efficiency from about 45 percent to 80 percent. With an average solvent content of conventional paints of 65 percent and assuming 25 to 30 percent fugitive losses, the overall emission reduction efficiency of this package (compared to the uncontrolled level) is estimated at about 65 percent. Due to the limited potential of spray operations, the applicability is restricted to about 40-45 percent.
- **Substitution** with alternative coatings (SUB). Based on an average solvent content of alternative coatings between 5 and 15 percent and assuming less use of cleaning solvent, the VOC reduction efficiency of this option is estimated at 77 to 88 percent. The actual applicability depends strongly on a number of specific factors, such as the availability of the substitute product (paint) for a particular process, the required quality of the finish, and the country-specific structure of the sector. It is presently estimated at 80 percent.
- **Add-on techniques** (A_INC) refer to thermal and catalytic incineration. With a typical removal efficiency of 95 percent, the applicability is critically influenced by flow rates and solvents concentrations of the air stream and the extent to which processes are enclosed. Usually, the application potential is limited, since only a fraction of the emissions from the entire plant can be treated. Activated carbon adsorption and 'biological bed' are further techniques belonging to this group; since the available literature suggests minimal applicability and high costs for these two options (ERM, 1996), they are, at the current stage, not included in the analysis.

Additionally, combinations of the above mentioned options are considered in the model.

3.2.6 Solvent Use in Chemical Industry

With data supplied by the majority of countries, CORINAIR'90 reports nearly 700 kt of VOC emissions from this sector (4 percent of total). Large differences and inconsistencies in emission factors, however, question the reliability of at least some of the available information, so that it was decided to wait for further information before introducing detailed sectoral distinctions into the RAINS-VOC module. For the time being, the sector was split into two broad categories distinguishing the different nature of processes:

- Chemical products incorporating solvents like paints, inks, glues;
- Products without solvents, such polyester, rubber, pharmaceuticals, etc. This sector was further subdivided into
  - Pharmaceutical industry (although not significant on the European scale, it is an important source of VOC emissions in a few countries), and
  - Other industry.

The full list of activities included in the sectors is provided in *Annex 1*.

3.2.6.1 Products Incorporating Solvents

PIS

CORINAIR'90 reported about 300 kt (1.6 percent of total) of VOC emissions from activities included in this category, of which more than half originated from the production of paints and glues *(CORINAIR SNAP'90 and '94 code 060307* and *060309*, respectively). Most of the other activities included in this category (compare *Annex 1*) contribute less than one percent to total national emissions.

The options to control emissions from this sector include the reduction of fugitive losses, reformulation of products, and a range of add-on techniques. Although various measures have been already introduced due to the occupational health and safety reasons, information on their efficiency and costs is scarce. RAINS considers the following control options:

- **Basic emission management techniques** (BEMT). This group of measures includes solvent management plans (SMP) and process changes, such as improved maintenance and the introduction of continuous instead of batch process (where possible), which can result in a substantial reduction of fugitive losses. The available literature (ERM, 1996; IFARE, 1998) suggests that such options are widely applicable (from 50 to nearly 100 percent) with typical control efficiencies in the range of 10 percent.
- Potentially a very attractive option, at least in paint production, is the **reformulation** (REF) (e.g., water-based coatings), which can bring emissions down by 30 to 95 percent (EPA, 1994). The applicability of this option is considered to be high, especially in the long term. In the past, some of the reformulated products did not meet the requirements expected by the users in terms of the quality of the coating and there still are problems related to the application of reformulated products for some purposes (see also Section 3.2.5.3). Much progress has been made over the last few years, so that for the long run an applicability of up to 80 percent of paint and glue production seems reasonable. Typical removal efficiencies are around 50 percent.
- **Add-on techniques** such as biological, catalytic and thermal oxidation. In principle, these options are characterized by high removal efficiencies (~95 percent) and could be widely applied. In practice, the achievable overall efficiency depends on the share of emissions that can be captured. RAINS assumes a combination of primary and add-on techniques (BEMT+A_INC) with an efficiency of 95 percent. An application potential of up to 75 percent is presently used in RAINS, depending on the structure of the sector in a given country.

3.2.6.2 Products Not Incorporating Solvents (Excluding Pharmaceuticals)

PNIS

This category covers a wide range of different processes, contributing in total about 300 kt (1.8 percent) to the European VOC emissions. The complete list of activities included in this category is provided in *Annex 1*. The largest portion (nearly 200 kt) originates from rubber and polyvinylchloride (PVC) processing *(CORINAIR SNAP'90&'94 code 060305* and *060302*, respectively).

While polyurethane and polystyrene foam processing *(CORINAIR SNAP'90&'94 code 060303* and *060304*, respectively) contributed in 1990 only about 10 percent, the replacement of CFC's by butane and pentane will increase their share in the future. Unfortunately, the control potential for these products is limited, because a substantial part of the emissions do not occur during production, but later during application.

As with all sectors where a wide range of different activities is included, the definition of a 'typical' or 'representative' control options is a difficult task. The values listed below refer to the average European situation, assuming fugitive losses of 20 percent. In practice, however, RAINS uses country-specific information to describe the actual situation and application potential for each individual country. RAINS distinguishes the following emission control options:

- **Solvent management plans** (SMP). The use of lids on tanks and/or improving the solvent delivery and handling system can reduce VOC emissions by up to 10 percent. The application potential varies between 25 to 80 percent across countries, depending on the state of technological development and legal requirements.
- **Add-on techniques** (A_INC), e.g., adsorption and thermal incineration, have proven to achieve very high efficiencies, typically above 95 percent. They could be widely applied, although only to a part of the process. RAINS assumes applicabilities of up to 70 percent.
- **Substitution** (SUB) is a viable option for rubber processing only. Thus its applicability will depend not only on the limitations within the rubber industry (estimated at about 25 percent), but also on the contribution of this industry to total emissions of this sector in a given country. Therefore, although the efficiency can be as high as 100 percent, the overall applicability will be typically around 5 to 10 percent. Effectively, this option is used in combination with solvent management plans (SMP+SUB) assuming an efficiency of 50 percent and an applicability to 30 percent of the sector.

3.2.6.3 Pharmaceutical Industry

Although the pharmaceutical industry *(CORINAIR SNAP'90* and *'94 code 060306)* does not make a major contribution to total European VOC emissions (about 0.7 percent), it is a non-negligible source for United Kingdom, Germany and Switzerland.

PHARMA

The only option for reducing VOC emission from this sector which is considered in RAINS is the **combination of primary measures** (good housekeeping and solvent management plans - HSE) **with add-on technologies** such as incineration or adsorption (INC/ACA). The efficiency of this package is estimated at 87 percent with full applicability to the entire sector. To get the abatement potential right, however, it is important to determine the country-specific situations (i.e., the already implemented control measures) in the base-year.

3.2.7 *Printing Industry*

VOC emissions from printing industry are caused by several activities such as publication of newspapers, magazines, books, etc., packaging (cardboard, flexible plastic, aluminum foils), and decoration (e.g., wallpapers). There are several techniques used in printing: litography, rotogravure, flexography, and screen printing (EEA, 1996; EEC, 1990; IFARE, 1998; Allemand *et al.*, 1990). Although the relative importance of these techniques for VOC emissions differs among countries, flexography and rotogravure are usually the most important processes. Since different abatement techniques will be used for various printing processes, four sub-sectors are distinguished in the RAINS model.

VOC emissions from printing industry from the 17 countries that reported to CORINAIR'90 *(SNAP'90*[16] *code 060403)* amount to nearly 300 kt (~1.7 percent of total emission reported, see Table 2). Consequently, in reality the printing sector might be responsible for a somewhat larger share of emissions.

3.2.7.1 Flexography and Rotogravure in Packaging

PRT_PACK PRT PACK NEW

Printing of milk cartoons, multiwall bags, labels, tapes, envelopes, as well as laminates and corrugated paperboard is often done with flexography and rotogravure techniques. A variety of substrates can be used, e.g., heavy paper, metal and plastic foil. For more detailed description of the processes see, e.g., IFARE, 1998; EEC, 1990; Allemand *et al.,* 1990.

Emissions of VOC originate from solvents contained in inks and from solvents used for cleaning the equipment. Control options include good housekeeping, modification of the process, ink substitution and, since a large proportion of emission occurs at the dryer, end-of-pipe measures.

The following major options for reducing VOC emissions from this sector are considered in the RAINS model:

- Use of **low solvent inks and enclosure** of the printing facility (LSI+ENC) is a cost-effective option with high applicability (up to 95 percent) and an efficiency estimated at about 65 percent.
- A **substitution with water based inks** (WBI). Characterized by an efficiency of about 90 percent, the application potential is severely limited (about 30 percent) by technical difficulties in flexible packaging.
- **Enclosure and solvent recovery** through carbon adsorption (ENC+ACA) proved to be an effective option to reduce emissions from larger plants if a single solvent is used. For smaller facilities, i.e., with an ink consumption below 500 t, this option is believed to be far too expensive (IFARE, 1998). In some countries this technique was already in use before 1990 for economic or occupational health reasons. For single plants, removal efficiencies around 90 percent are documented in the literature. In the RAINS model, the average efficiency for the whole sector is

[16] In SNAP'94, further subdivision into four major categories was introduced, i.e., flexography and rotogravure in packaging, heat set offset, rotogravure in publication, and screen printing.

assumed at 75 percent, since only part of the emissions can be captured. The applicability is limited to about 20 percent, and it is assumed that this option will become part of new installations, as far as applicable.

- **Enclosure and thermal incineration** (ENC+INC) is characterized by high removal efficiency (90 to 95 percent) and can be widely applied (it is already in use in some countries). However, owing to the fact that about 20 percent of emissions are fugitive losses, the overall efficiency is likely to be about 75 percent and applicability up to 95 percent.

Also combinations of the above options are considered in the model.

3.2.7.2 Rotogravure in Publication

PRT_PUB PRT_PUB_NEW

This process can be applied to print on various substrates, including coated and uncoated paper, film, foil, etc. It is widely used in publication, especially in advertising, and printing magazines, catalogues, newspaper supplements. At present, mostly solvent borne inks are used in publication. Details of process can be found in IFARE, 1998; EEC, 1990; Allemand *et al.*, 1990.

Similarly to the sector described in the section above, emissions occur from the use of inks and cleaning solvents. Since the process is similar, also the control options are of the same type.

The following categories are considered in the model:

- Use of **low solvent inks and enclosure** of the printing facility (LSI+ENC) is a cost-effective option with high applicability (up to 80 percent) and an efficiency estimated at about 50 percent.
- **Substitution with water based inks** (WBI) can reduce VOC emissions by up to 90 percent. While still under research, the application potential is rather small (about 20 percent) due to the lower quality of the finish.
- **Enclosure and solvent recovery** through carbon adsorption (ENC+ACA) proved to be an effective option to reduce emissions and has been successfully applied in some countries already in the 90's. RAINS assumes an efficiency of 75 percent and applicability to nearly the entire capacity. Enclosing the process, reducing the solvent content of inks and recovering solvents is assumed to be an integral part of new installations.

3.2.7.3 Screen Printing

PRT_SCR PRT_SCR_NEW

This technique is applied especially for printing on paper of large advertisements, prospects, etc., as well as on other substrates like PVC (polyvinylchloride), textiles, glass, and plastics (EEA, 1996).

Emissions originate primarily from the printing inks (no dilution required) and from the solvents used for cleaning. Control options include water based and 'solvent-free' inks, catalytic incineration as well as biofiltration.

The following categories are distinguished in the RAINS model:

- **Substitution with water based inks** (WBI) has a wide application potential (assumed up to 90 percent) and an efficiency of 75 percent.
- **Enclosure and catalytic incineration** (ENC+INC) is characterized by high efficiency, i.e., 90 to 95 percent. However, owing to the fact that about 20 percent of emissions are fugitive losses, the overall efficiency is likely to be about 75 percent. This option will be typically applicable to large and medium installations, so that its potential is estimated at about 60 percent;
- **Biological treatment** (bio-filters, bio-scrubbers) (BIO) is a high efficiency option (about 95 percent) that can be applied in large plants. Due to the relatively large share of small plants in most countries, the potential of this control technique is estimated at only 30 percent.

The composition of ink can be also changed to allow UV, infra-red or radiation curing. These methods would often use inks that contain almost no solvents and could therefore cause only very little, if any, emissions of VOC (IFARE, 1998). It is expected that these processes will penetrate with time and it is assumed in RAINS that up to 10 percent of new capacity [PRT_SCR_NEW] will apply these techniques.

3.2.7.4 Offset Printing

PRT_OFFS PRT OFFS NEW

Offset printing is used to print magazines, catalogues, newspapers, etc. Emissions can be reduced by various primary measures, solvent management plans, 'solvent-free' inks, and end-of-pipe measures (IFARE, 1998; Allemand *et al.*, 1990). Three principal categories are distinguished in the model:

- **Primary measures and enclosure** (PMOF). This option includes good housekeeping (modified practices for handling, storage and cleaning of equipment), reduction of isopropanol consumption, optimization of the dampening system, use of vegetable oil-based cleaning agents, as well as enclosure. It is assumed that such measures are applicable to the whole sector and achieve removal efficiencies of about 30 percent.
- **'Solvent free' inks and solvent management plan** (SF+SMP). 'Solvent free' inks (radiation curing) are characterized by a high efficiency reaching 95 percent, but have limited applicability (assumed 10 percent).
- **Enclosure and thermal incineration** (ENC+INC) is a very effective option to reduce emissions of VOC and can be applied to many installations. RAINS assumes an average efficiency of 75 percent and an applicability of up to 80 percent.

Additionally, combinations of the techniques listed above are included in the model.

It is also assumed that up to 10 percent of the new constructed capacities will use radiation curing (thereby using 'solvent free' inks) and that all new installations will introduce primary measures (see PMOF).

3.2.8 Other Use of Solvents in Industry

This category includes several industrial activities that are grouped in RAINS into three major sectors, i.e., application of glues and adhesives, preservation of wood, and other industrial use of solvents. Details are provided in the text below as well as in Table 2 and Annex 1.

For 1990, more than 900 kt of VOC emissions are reported from this sector, i.e., nearly 6 percent of total anthropogenic emissions in Europe. Due to inconsistent reporting of the emissions from *other use of solvents (CORINAIR SNAP'90 code 060400)*, it is difficult to estimate the real emissions from the individual sectors. For this work it was assumed that more than 30 percent of the emissions result from *application of glues and adhesives,* 20 percent from *preservation of wood*, and the rest from other sectors classified in this group, mostly *fat edible and non-edible oil extraction.* In some countries other sectors like leather tanning, textile finishing or use of agrochemicals might be of some importance, which is reflected in control options available for this sector.

3.2.8.1 *Application of Glues and Adhesive*s

GLUE

This category *(CORINAIR SNAP'90* and *'94 code 060405)* comprises a wide range of processes and is characterized by many small enterprises and only a few large and medium size companies (Jourdan and Rentz, 1994). VOC emissions of this sector are estimated at about two percent[17].

The control options considered in RAINS are:

- **Modification of the application technique** (brushing, rolling, spraying) to improve the transfer efficiency, and other housekeeping measures (HSE). The typical reduction efficiency is estimated at 15 percent. The applicability will vary, depending on the size of plants.
- **Substitution** (SUB) with water-based adhesives or hot melts. The substitution with water based products is expected to be applicable to about 60 percent of the activities with an efficiency of about 85 percent. However, the use of water-based adhesives might have, in some cases, adverse impact on the quality of the finished product. Therefore, literature suggests hot melts as the more promising option with similar efficiency and applicability.
- Among the '**add-on techniques'**, thermal oxidation (INC) seems to be the most appropriate one. The assumed reduction efficiency is about 80 percent. The application potential is limited to continuously operating large installations. Currently an applicability of 40 percent is used in the model.

In addition, the model considers combinations of the above options.

Since the available information on some other options such as the *atmospheric pressure non-equilibrium technique* is still scarce, they are not considered in RAINS at this stage.

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[17] Although Table 2 indicates that emissions from this category contribute only 1.1 percent to total, some countries included emissions from this activity under *SNAP level 2 (060400).*

3.2.8.2 Preservation of Wood

WOOD
WOOD NEW

Emissions of VOC from wood preservation *(CORINAIR SNAP'90* and *'94 code 060406)* occur during handling, application and drying stages, the latter usually done in the open air. These activities account for about 1.2 percent[18] of total anthropogenic VOC emissions in Europe with the largest contribution coming from the drying process.

Emissions can be reduced by solvent management plans (including measurement programs monitoring the losses of solvents), enclosing the process wherever possible and applying add-on techniques (condensation plant, carbon adsorption and regenerative thermal oxidizers), as well as using low solvent preservatives where applicable. Options considered in RAINS include:

- **Double vacuum impregnation system** (DVS) and **enclosure** of the drying stage (ENC). It is assumed that this combination is applicable to the whole sector and that it will become an integral part of new-built plants. The efficiency of this option is estimated at about 40 percent as it applies to parts of the total process and to fugitive emissions.
- **Add-on techniques** like incineration (INC) and adsorption (ACA) is applicable to most of the sector, but only able to capture parts of total emissions. The overall efficiency is assumed at about 60 percent.
- **Combinations** of the above options, with reduction efficiencies of about 75 percent, applicable to the whole sector.

Literature indicates that abatement potentials and costs will vary substantially between small and large installations (IFARE, 1998; ERM, 1996). Due to scarce information on size distribution and the fact that the contribution to total emissions is at most 1.5 percent, no further disaggregation of this sector is done at the moment.

3.2.8.3 Other Industrial Use of Solvents

IND_OS

This group comprises a number of processes with varying importance in different countries, in total responsible for emissions of about 400 kt in 1990. In the majority of countries the most important single activity is '*Fat edible and non-edible oil extraction*' *(CORINAIR SNAP'90* and *'94 code 060404).* In countries reporting emissions from this activity the contribution to national total ranges between one and a few percent.

It is worth mentioning that in some cases countries reported to CORINAIR'90 significant VOC emissions under '*Other use of solvents and related activities*' *(CORINAIR SNAP'90 code 060400)* and '*Glass wool enduction*' *(CORINAIR SNAP'90 code 060401).* It was not always possible to identify the real sources. In CORINAIR'90, the SNAP categories 060400 and 060401 were often used as surrogate categories to report emissions from other sources like leather tanning, textile industry, paper

[18] As in the case of *application of glues and adhesives in industry* the contribution of *preservation of wood* reported in Table 2 is lower (0.8%), the reason being aggregated reporting on the *SNAP 2* level (see also previous footnote).

production, etc. Only later, these activities received their 'own' codes, i.e. *SNAP'94 060312,13* for textile finishing and leather tanning, and use of agrochemicals *(SNAP'94 060412).*

Emissions from '*Fat edible and non-edible oil extraction*' can be controlled by improving the efficiency of the solvent extraction and by adding abatement equipment like water scrubbers at the drying plant. RAINS distinguishes two categories of control options to this activity (the applicability depends on the relative contribution of this category to total emissions in the sector):

- **Primary measures** (PRM) with an efficiency of about 70 percent.
- A **combination** of **primary measures and add-on technology,** e.g., bio-filtration (PRM+BIO) with an efficiency of 75 percent.

Additionally, two other options are included in this sector. They refer to the activities that are important sources of emissions in some countries, namely leather tanning and the use of agrochemicals.

- Reformulation of leather coatings, i.e., **waterborne coating** (WBC). This option has already been used by some operators in Europe (Passant and Vincent, 1998) and its estimated reduction potential is around 60 percent.
- Introduction of **new agrochemical products** (NAGR) with lower solvent content allowing lower application dosage rates (ERM, 1996). It is expected that solvent use in the sector will drop by 30 to 50 percent (assumed 40 percent).

3.3 Chemical Industry

The contribution of chemical industry (excluding solvent use) to total anthropogenic NMVOC emissions in 1990 was about 500 kt (~3 percent). In RAINS, this sector is split into two major categories: (i) production processes and (ii) storage and handling of chemical products. Production processes are split further into inorganic (fertilizer production and other products) and organic chemical industry, the latter contributing three-quarters of the process emissions.

3.3.1 Production Processes in Inorganic Chemical Industry

INORG

The inorganic chemical industry, particularly the production of carbon black, nitrogen fertilizers and nitric acid, caused about 120 kt of VOC emissions in 1990 *(CORINAIR SNAP'90* and *'94 codes 040402-09).* There is some doubt about the reported emissions from fertilizer production; experts suggest somewhat lower figures to be realistic.

At the time of writing no information on options for reducing VOC emissions was available.

3.3.2 Production Processes in Organic Chemical Industry

ORG_PROC

Around 300 kt of NMVOC (~1.7 percent of total) were reported in 1990 for the manufacturing of several chemicals *(CORINAIR SNAP'90* and *'94 code 040501-21)*; for the complete list see *Annex 1*. Emissions occur through venting, storage, handling, leakage, sampling, spillage, etc. Nearly 70 percent of these emissions are caused by the production of ethylene, propylene, polypropylene, and polyethylene (low and high density). The importance of this sector in different countries varies from 0.5 to about 5 percent.

The control techniques applicable to this sector include process modifications, leak prevention programs, improved flare and add-on techniques like thermal and catalytic incineration, adsorption, absorption, and condensation. These techniques are grouped into the following categories:

- **Reduction of vent losses** and regular monitoring and inspection programs to prevent equipment leaks (LK_I, LK_II). The efficiency of this package is estimated at 60 to 70 percent. Country-specific information on applicability is scarce; for the time being 20 percent is used in RAINS.
- **Flaring** (FLR) could reduce venting losses by about 85 to 90 percent. The applicability is determined by the amount of venting losses (between 20 and 40 percent of total emissions from this sector).
- **Add-on techniques** include mainly thermal and catalytic incineration (INC) with reported efficiencies of typically 96 percent. Applicable only to a part (50 percent) of the process.

Combinations of these options are also considered in the model.

CORINAIR'90 does not report (or reports only inconsistently) emissions of individual processes (venting, storage, handling). It is difficult to exactly determine the application potentials for individual countries. Based on information from the CORINAIR'90 inventory there is a great variability in the types of chemicals manufactured and in the technical characteristics of the manufacture processes. A further complication arises for the assessment of the current control level, since in many countries various control options are already integrated in the production process, following, for example, regulations related to occupational health. Finally, also the flow rates and VOC concentrations of the gas streams, which significantly influence the applicable control options, are largely unknown.

3.3.3 Storage and Handling of Chemical Products

ORG_STORE

CORINAIR'90 reports about 80 kt of VOC emissions (0.5 percent) from storage and handling of chemical products *(CORINAIR SNAP'90* and *'94 code 040522)*. However, this number only contains submissions from about one third of the countries; it is believed that the other countries subsumed the emissions either under the category '*processing in organic chemical industry' (SNAP level 2 - 0405)* or included them in the emissions from processing of chemicals. This makes it difficult to derive reliable estimates based on the current submissions to CORINAIR inventory. It is, however, important to distinguish this source from the chemical industry since the applicable control options are quite different from those used to abate emissions in the processing part.

For the countries reporting emissions under this category RAINS distinguishes two options for reducing emissions:

- Introduction of **internal floating covers** and **secondary seals** (IFC) with efficiency of 90 percent and applicability varying typically between 10 and 20 percent;
- **Vapor recovery units** (VRU), efficiency 95 to 99 percent, depending if single stage (VRU_I) or double stage (VRU_II) recovery units are applied.

In addition, a **combined application** of both options is foreseen in the model.

3.4 Oil and Gas Industry

CORINAIR'90 reports about 1.5 million tons of VOC emissions from the oil and gas industry, i.e., nine percent of total European VOC emissions. RAINS distinguishes three major categories (extraction and distribution of liquid and gaseous fuels, refineries, and gasoline distribution) which are further split into a total of seven sectors.

3.4.1 Fuel Extraction and Distribution

EXD_GAS
EXD GAS NEW
EXD LQ
EXD LQ NEW

Losses during loading and transport operations, direct venting and fugitive losses are the major sources of VOC emissions from the extraction of oil and gas and gas distribution *(CORINAIR SNAP'90* and *'94 codes 0502-04,06)*. For all of Europe, these activities contribute about 4.5 percent to total emissions; however, this share can be significantly higher in individual countries, particularly in countries with off-shore activities.

RAINS assumes that emissions from the existing gas distribution network cannot be controlled. However, as the mains will be gradually replaced the losses will be reduced by approximately 95 percent (ERM, 1996) at no extra cost.

Regular maintenance programs can reduce fugitive emissions; recovery systems installed in, e.g., marine tankers can capture losses during loading and transport. Emissions from venting may be reduced by flaring, through recovery or by a combination of both measures. RAINS distinguishes between existing and new installations for oil and gas extraction and loading and characterizes them by different emission factors. *New loading and unloading procedures* (assumed to become standard for new installations, i.e., sector EXD_LQ_NEW) can cut emissions from these operations by about 25 percent at no extra cost.

When evaluating the applicability of control options, it is important to consider that in many cases adding extra equipment (e.g., flares) might prove difficult or impossible due to space limitations and the inability to increase the topside weight of the platform.

The following control options are currently considered in RAINS:

- **Vapor balancing** (VBAL) on tankers and loading facilities with an efficiency estimated at 78 percent. This option is applicable to shipping emissions which typically represent 40 to 80 percent of the total emissions from the sector.
- **Venting alternatives** and **increased recovery** (V_ALT). Literature suggests a control efficiency of 90 percent, but applicable to only 5-15 percent of the emissions.
- **Improved ignition system on flares** (F_IMP). Efficiency 62 percent but, similarly to the previous option, applicable to a relatively small part of the emissions (few to possibly 20 percent, depending on the installation).

Combinations of the above options are also considered in the model.

3.4.2 Refineries (Excluding Storage of Products)

REF_PROC

Emissions from refineries *(CORINAIR SNAP'90* and *'94 code 040101-03,05)* can occur at nearly any part of the refinery production including processing, flaring, waste water treatment, storage of products, etc. The contribution of this sector to total European VOC emissions in 1990 was estimated at around 160 kt (~0.9 percent), although about 25 percent of all countries that reported to CORINAIR have not reported emissions for this activity.

Potentially leaking equipment includes tanks, pumps, compressors, valves, pressure-relief devices, flanges, etc. To reduce the fugitive emissions, leak detection and repair programs can be introduced. Its efficiency and cost will depend on the size of the installation, the monitoring method, frequency of inspection (quarterly, monthly), etc. Emissions from waste water separators can be reduced by minimizing the oil leakage to the sewage system and by introduction of floating covers on the separators. The gases and vapors that escape from the blowdown system and some process losses can be fed to a gas collecting system and consequently incinerated (IFARE, 1998).

RAINS distinguishes three main categories of options (and their combinations) for reducing emissions from refineries:

- Regular **inspection and maintenance** programs (LK_I and LK_II) with an assumed efficiency of 60 and 70 percent, respectively. These efficiencies are somewhat more conservative than what is suggested in some studies for Germany (EEC, 1990). The applicability of this option is determined by the share of fugitive emissions, and it typically varies from few to nearly 20 percent of total emissions.
- **Covers on oil/water separators** (COWS). Literature suggests efficiencies of about 90 percent (ERM, 1996, IFARE, 1998). However only about two percent of the emissions from refineries originate from this part.
- **Combustion** of the non-condensable emissions from the blowdown systems in a flare (FLR) with an efficiency of 98 percent (IFARE, 1998).
- A **combination** of the above option with added incineration (FLR-I) of other non-condensable vent emissions with an overall efficiency of 99 percent.

3.4.3 Gasoline Distribution

NMVOC emissions can occur at nearly every stage of the gasoline distribution chain, i.e., at bulk storage tanks (border terminals, refinery, marketing depots), at service stations, during transport and vehicle filling, and there is a range of possibilities where fugitive emissions can occur (spillage, etc.). It was decided to include in this RAINS sector also emissions from the storage of products at the refinery. Together this activities account for about 700 kt of VOC emissions in Europe (4 percent of total).

RAINS divides this sector into two categories:

- Transport and depots, including storage at the refinery, dispatch station and marketing installations, and
- service stations, including refueling.

3.4.3.1 Transport and Depots

D_REFDEP

This sector includes emissions from gasoline marketing and storage at refineries and dispatch stations *(CORINAIR SNAP'90* and *'94 codes 040104, 050501, 050502).*

Emissions from storage can be reduced for example by installation of internal floating covers for fixed roof tanks or secondary seals for tanks with external floating roofs. To achieve higher reductions, vapor recovery systems need to be installed. Modification of loading techniques (introduction of submerged top loading and bottom loading) and introduction of vapor return/recovery lines can reduce emissions from tank trucks, rail cars, barges, ships during loading operations. Combined vapor recovery systems and modified loading techniques are often referred to as STAGE IA controls. The options considered in RAINS are listed below:

- **Internal floating covers** (IFC) for fixed roof tanks or **secondary seals** for tanks with external floating roof (EFR) with an assumed efficiency of 85 percent.
- **Stage IA controls**, i.e., vapor balance lines and vapor recovery units at the refinery terminals. Single stage (ST_IAS) achieves a 95 percent reduction, for double stage (ST_IAD) a 99 percent reduction is assumed.

Combinations of these options are also considered.

3.4.3.2 Service Stations

D_GASST

At the service station *(CORINAIR SNAP'90* and *'94 code 050503)* emissions occur from storage tanks and can be controlled by vapor balancing systems (referred to as Stage IB) with demonstrated efficiencies of 95 percent.

Another source of emissions at service stations is the refueling of cars, which can be controlled by introduction of passive or active vapor balancing systems between the automobile fuel tank during refueling and the service station tank, often referred to as Stage II. The efficiency of this system depends on many technical and 'human' factors. If operated properly, efficiencies of up to 85 percent have been demonstrated (CONCAWE, 1990; Chem Systems, 1996). Investment and operating costs show strong relations to the size of the installation (e.g., annual throughput less/above 2.5 million liters/year). To derive country-specific abatement costs, data on the average throughput of gasoline stations in several European countries provided by CONCAWE were taken into account.

A viable alternative to Stage II controls is the installation of enlarged on-board carbon canisters in vehicles. It is expected that this measure can reduce refueling emissions by up to 95 percent. This option, however, is not included as yet in the model because the available literature is inconclusive, particularly about the transferability of American experience (CONCAWE, 1988; Chem Systems, 1996). Its long implementation time is a further disadvantage.

To summarize, the following technologies are recognized in RAINS:

- **Stage IB controls** (vapor balancing systems) with an efficiency of 95 percent.
- **Stage II systems** (vapor balancing system between a vehicle and service station tank), assumed efficiency of 85 percent.

Also the combination of both options is considered.

3.5 Stationary Combustion

Emissions from stationary combustion sources accounted for about seven percent of total anthropogenic emissions of NMVOC in Europe in 1990. All countries reported emissions of NMVOC from these activities to CORINAIR'90.

There are three major sectors distinguished in RAINS which are further subdivided into emission categories that are consistent with structure of the RAINS modules for sulfur dioxide (SO_2) and nitrogen oxides (NO_x):

- Public power, cogeneration, district heating plants
  - Existing plants, wet bottom boiler — PP_EX_WB
  - Existing plants, other types — PP_EX_OTH
  - New plants — PP_NEW
- Commercial and residential combustion — RESID
- Industrial combustion
  - Boilers — IN_BO
  - Other industrial combustion — IN_OC
  - Combustion in conversion sector — CON_COMB

No control options are considered for these sectors in the RAINS VOC model so far, except for residential combustion.

3.5.1 Commercial and Residential Combustion

RESID

The major source of VOC emissions from this sector *(CORINAIR SNAP'90* and *'94 codes 0201, 0202, 0203)* is the combustion of fuelwood and coal, especially in small boilers (used in single-family houses) and stoves. CORINAIR'90 reports emissions of nearly one million ton of VOC in 1990 (~6 percent of total). This number is fairly uncertain since, in many countries, the quality of the statistical information on fuelwood consumption in residential sector is poor. There is, however, no doubt that this sector is a significant source of VOC. In fact, policies of increasing the use of renewable energy sources might result in increased consumption of wood and thereby lead to higher emissions of VOC if, at the same time, the currently operated stoves and small single-family house and residential-commercial boilers will not be replaced by modern design facilities.

There is a number of ways in which the combustion efficiency could be increased and emissions reduced. A modern wood fired boiler with an accumulator tank has an efficiency of 75 to 85 percent compared to only 50 percent of the older installations, and the best available boilers of this type could achieve efficiencies above 90 percent (IFARE, 1998; NUTEK, 1997). Replacing old with the new boilers can reduce VOC by up to 96 percent (NUTEK, 1997). To be on the conservative side, RAINS assumes a lower average removal efficiency to reflect the variety of boilers currently used across Europe and provide for non-optimal operating conditions of the equipment in the domestic sector (see also IFARE, 1998).

Other methods for improving the performance of old boilers include external furnaces, ceramic inserts and pellet burners (IFARE, 1998; NUTEK, 1997). Also secondary measures like oxidation catalysts can be applied, achieving VOC removal efficiencies between 30 and 80 percent (IFARE, 1998). It has to be stressed, however, that there are certain problems that limit the applicability of this option to mostly low-emission modern boilers, e.g., dust deposition on the catalyst, deposits of tar from the raw gas and the sensitivity of the catalyst to hydrochloric (HCl). Some of the problems have been successfully solved in modern installations and this option is successfully used in the USA.

Two categories of control options for installations where coal and fuelwood is combusted are included at this stage in RAINS:

- Oxidation **catalysts** (CAT) with an efficiency of 50 percent.
- **New boilers** with accumulator tank (NB) with an average efficiency of 80 percent.

3.6 Transportation

In principle, options for reducing VOC emissions from transport activities are treated in the separate RAINS module for mobile sources, since many of these options simultaneously reduce NO_x and VOC emissions. There are, however, few transport categories for which specific VOC control measures[19] exist. For methodological

[19] In fact, often other pollutants are also reduced, e.g., carbon monoxide (CO) in case of oxidation catalyst, but they are not included in the RAINS model as yet.

reasons, these control options are treated in the RAINS VOC module, despite its main focus on stationary sources.

Such sources include evaporative losses from cars (see Section 3.1), two-stroke gasoline engines, shipping and air traffic. Other traffic sectors, i.e., passenger cars, light-duty trucks, heavy duty trucks, busses, etc., are included in the RAINS-NO_x module and described in Cofala and Syri, 1998.

3.6.1 Two-stroke Gasoline Engines

TRA_RD_LF2
TRA_OT_LF2

Uncontrolled two-stroke gasoline engines are characterized by very high VOC emissions rates (compare Table 6 in Section 2.2.1). This type of engines are used in cars and mopeds and in some off-road machinery, i.e., lawn mowers, motor saws used in forestry, etc. It is difficult to estimate the total emissions from these engines since detailed statistical information on fuel consumption is not available and the CORINAIR inventory does not distinguish this category separately. However, it can be assumed that most of the emissions reported in the category 'motorcycles and mopeds' *(CORINAIR'90* and *'94 code 0704)* originate from two-stroke engines and include a small share of passenger cars and off-road machinery. For 1990, VOC emissions from these sources were estimated between 500 and 1000 kt, representing between 3 and 6 percent of total anthropogenic emissions in Europe. The importance of this category varies from country to country depending, i.a., on the number of mopeds as the main contributors.

RAINS distinguishes the following two sub-sectors:

- two-stroke engines used in road transport [TRA_RD_LF2] and
- two-stroke engines used in off-road machinery [TRA_OT_LF2].

With oxidation catalysts tailpipe emissions of VOC from two-stroke engines can be reduced by up to 90 percent (OECD, 1995). Oxidation catalysts reduce hydrocarbon and carbon monoxide emissions. Already in the 1970's this technology was used in cars, mostly in the USA. Further reduction of hydrocarbons might be possible through advanced injection systems, i.e., direct-cylinder electronic fuel injection (OECD, 1995), although this technology is not yet considered in RAINS.

RAINS includes only one control technology for two-stroke engines, i.e., **oxidation catalysts** (OX_CAT) that can be applied to both road and off-road engines. The average efficiency of this option is assumed at 80 percent.

3.6.2 Shipping and Air Traffic

According to the CORINAIR'90 inventory, inland shipping *(CORINAIR'90 and '94 SNAP code 0803)* and air transport *(CORINAIR'90 SNAP code 0805* and *SNAP'94 codes 080501,02)* do not belong to the major sources of VOC emissions, contributing 0.9 and 0.4 percent of total VOC in Europe in 1990, respectively.

RAINS distinguishes the following sub-sectors:

- Inland shipping
  - medium size ships — TRA_OTS_M
  - large size ships — TRA_OTS_L
- Air transport (landing and take-off only) — TRA_AIR

At this stage RAINS does not consider any control technologies for these categories.

3.7 Miscellaneous Sources

In 1990, miscellaneous sources (agriculture, waste treatment and disposal, food and drink industry, and other industrial sources) accounted for one million tons of VOC. This represents about six percent of total anthropogenic emissions of NMVOC in Europe in 1990. About half of these emissions originated from burning of stubble and other agricultural waste.

3.7.1 Food and Drink industry

FOOD

This sector includes emissions from the production of bread, beer, wine and spirits. Although some studies indicate that meat and other food processing might be an important source of emissions too, this is not supported by data from the CORINAIR'90 inventory. In most countries between 50 to 80 percent of these emissions come from bread manufacturing *(CORINAIR'90* and *'94 SNAP code 040605)*. The production of alcoholic beverages *(CORINAIR'90* and *'94 SNAP codes 040606-08)* are reported as important sources in a few countries, e.g., France and the UK.

Possibilities for controlling VOC emissions include good housekeeping, incineration and for the food industry biological treatment. The efficiency of the add-on options is high (between 80 and 90 percent), but there are some limitations to the applicability. RAINS considers **add-on measures** (INC) with an average efficiency of 90 percent; the applicability depends on the relative share of emissions from bread production.

Most of the emissions from alcohol beverages manufacturing result from maturation. They are usually not controlled and it is believed that emission controls might have an impact on the quality of the final product. Possible options include ducting emissions from the warehouse either for adsorption and recovery or destruction. This, however, requires changes to the design that appear as practical only for new warehouses.

3.7.2 Other Industrial Sources

IND_ORH

Other industrial sources are responsible for about one percent of total anthropogenic NMVOC emissions; about 50 percent of them result from wood and paper pulp production *(CORINAIR'90* and *'94 SNAP codes 040602,03)*. Iron and steel industries and collieries *(CORINAIR'90* and *'94 SNAP code 0402)* contribute about 30 percent (mostly from coke oven and rolling mills), and asphalt production and use *(CORINAIR'90* and *'94 SNAP codes 040610,11)* another 20 percent. The contribution of the above industries varies from country to country.

There is only little experience with control options for these sectors, and there is hardly any documentation about it. Since the majority of emissions from iron and steel industry is of fugitive nature, improved coke oven door operation, regular maintenance and reduced oil content of lubricants used in rolling mills will result in substantially lower VOC emissions. Reduction efficiencies of this 'good housekeeping' options are reported to vary between 40 and 80 percent (IFARE, 1998). In the paper and pulp industry mostly end-of-pipe options would be applicable. To reduce emissions from asphalt application (road construction) substitution of cutback by emulsion bitumen is a possible option. Information on efficiency and costs of this option is given in ERM (1996), IFARE (1998), and Passant and Vincent (1998).

Options currently considered in RAINS include:

- **Good housekeeping** (HSE) with an efficiency between 30 to 60 percent and an applicability of up to 70 percent depending on the structure of emissions in a given country.
- **Bitumen substitution** (BISUB) with an efficiency of 92 percent. The applicability depends on the relative share of this sector to total emissions in a country. It is assumed that up to 70 percent of cutback bitumen can be substituted.

3.7.3 Remaining Sources

CORINAIR'90 reports 550 kt of NMVOC (~3.3 percent of total) from other anthropogenic sources not listed in the sectors discussed before.

3.7.3.1 Stubble Burning and Other Agricultural Waste

AGR_BURN

For this sector *(CORINAIR'90* and *'94 SNAP codes 090700, 1003)* about 2.6 percent of total NMVOC emissions were reported for 1990. There are no technical control options available. A non-technical measure considered in the model is the introduction of a **ban on straw burning** (BAN). The applicability and enforcement of prohibiting waste burning in the open field has to be evaluated in close relation to its practical consequences. It is assumed in the model that this option has a 100 percent efficiency (if enforced) and in the long-term an applicability of 90 percent.

3.7.3.2 Waste Treatment and Disposal

WASTE

The share of this sector *(CORINAIR'90 codes 090100; 090201,02,04,05; 0904* and *'94 SNAP codes 090100; 090201,02,04,05,06,08; 0904)* in total VOC emissions is below one percent (~100 kt). The main sources are landfills and wastewater treatment facilities. Emissions of NMVOC from landfills contribute about 50 percent and, potentially, they can be controlled. It is assumed that '**new landfill technologies**' (I_LAND), including the collection and utilization of landfill gas, can cut VOC emissions by 20 percent.

3.8 Summary of Control Options' Categories and Their Efficiencies

Table 7 summarizes categories of control options that are considered in the RAINS model for the various sectors. For the sake of brevity, this table does not display all options that are considered in the model for each of the sectors, specifically many of the possible combinations of control technologies are not displayed. Full information about all options for every country can be found on the RAINS web site (http://www.iiasa.ac.at/~rains/databases.html).

As stated before, the technical efficiencies of control options used in the model are not country-specific. However, for some of the options listed in the table below ranges are given for the technical removal efficiencies, reflecting the situation that in some sectors the contribution of 'parts' or processes (included in a considered sector) to total emissions varies from country to country, leading to different 'starting points'.

Table 7: Efficiencies of the major categories of VOC abatement measures for the source categories distinguished in the RAINS-VOC module

Sector	Control option	Efficiency [%]
	Solvent use	
Dry Cleaning	Good housekeeping and adsorption	60
	Closed circuit conventional or new machines	76/92
Degreasing operations	Basic emission management techniques	20
	Carbon adsorption	80
	Low temperature plasma process	98
	Conveyored degreaser with integrated adsorption	95
	Water based systems	99
Domestic solvent use	Substitution	~25
Non-industrial paint use	Emulsions/dispersion paints	85-95
	Water based paints	70-80
	High solids	40-60
Industrial paint use (car manufacturing)	Good housekeeping, application technique modification	~65
	Process modification and substitution	70-88
	Adsorption, incineration	95
Vehicle refinishing	Good housekeeping, application technique modification	~24
	Housekeeping, application technique, substitution	45-72
Products incorporating solvents	Reformulation	50
	Basic emission management and end-of-pipe	95
Products not incorporating solvents	Solvent management plan and substitution	50
	End-of-pipe (adsorption, incineration)	95
Pharmaceutical industry	Good housekeeping and end-of-pipe	85-90
Printing		
Packaging	Low solvent inks and enclosure	65
	Water based inks / (new installations)	90
	Enclosure and adsorption	75
	Enclosure and incineration	75
Publishing	Low solvent inks and enclosure	50
	Water based inks / (new installations)	90
	Enclosure and adsorption	75
Screen printing	Water based inks	75
	Enclosure and incineration	75
	Water based inks and biofiltration	95
Offset	Primary measures	30
	'Solvent free' inks and solvent management plan	95
	Enclosure and incineration	75

Sector	Control option	Efficiency [%]
Glues and adhesives in industry	Good housekeeping Substitution Incineration	15 85 ~80
Preservation of wood	Double vacuum impregnation & dryer enclosure As above plus end-of-pipe	40 75
Other industrial use of solvents	Process modification and biofiltration Water based coating (leather tanning) New agrochemical products	75 ~60 ~40
	Chemical industry	
Organic chemical industry, processing and storage	Quarterly, monthly inspection and maintenance programs Flaring Incineration Internal floating covers and secondary seals Vapor recovery units	60/70 85-90 96 90 95/99
	Liquid fuel extraction, processing and distribution	
Fuel extraction, loading and transport	Venting alternatives and increased recovery Improved ignition system on flares Vapor balancing on tankers and loading facilities	90 62 78
Refineries	Quarterly, monthly inspection and maintenance programs Covers on oil/water separators Flaring / Incineration Internal floating covers and secondary seals Vapor recovery units (Stage IA) - single/double stage systems	60/70 90 98/99 85 95/99
Fuel storage and distribution	Internal floating covers and secondary seals Vapor recovery units (Stage IA) - single/double stage systems Stage II Stage IB	85 95/99 85 95
	Transport and combustion	
Gasoline evaporation 2-stroke engines Residential combustion	Small carbon canister Oxidation catalyst New boilers Catalyst	85 80 80 50
	Miscellaneous	
Food and drink industry Agriculture Other industrial Waste disposal	End-of-pipe Ban on burning waste Good housekeeping Bitumen substitution Improved landfills	90 100 30-60 92 20

4 Cost Calculation

This section introduces the methodology for calculating emission control costs in the RAINS-VOC module. The approach is in line with the methodologies currently applied in RAINS for the calculations of SO_2, NO_x, and ammonia emissions (Cofala and Syri, 1998ab, Klaassen, 1991).

The basic intention of the cost evaluation is to identify the values to society of the resources diverted in order to reduce VOC emissions in Europe. In practice, these values are approximated by estimating costs at the production level, rather than prices to the consumers. Therefore, any mark-ups charged over production costs by manufacturers or dealers do not represent actual resource use, and are ignored. Certainly, there will be transfers of money with impacts on the distribution of income or on the competitiveness of the market, but these should be removed from a consideration of the efficiency of resource. Any taxes added to production costs are similarly ignored as transfers.

The specific cost data as well as other parameters used in cost calculation for the considered control options are derived from several international and national projects and studies (IFARE, 1998; ERM, 1996; Allemand *et al.*, 1990; DFIU, 1996; Bouscaren *et al.*, 1998; Chem Systems, 1996; EPA, 1994; Hein *et al.*, 1994; NUTEK, 1997; OECD, 1992; Oonk, 1995; Passant and Vincent, 1998; VROM/DGM, 1995, 1997; Wenborn *et al.*, 1995) and from information provided by many national experts.

The following sections introduce principles of cost calculation in RAINS and explain the construction of the cost curves that are further used in the optimization module of the RAINS model. The actual parameter values used to calculate country-specific costs and the national cost curves are provided on the RAINS web site (http://www.iiasa.ac.at/~rains/databases.html). Section 4.3 gives an overview of the range of unit costs calculated in RAINS for the major categories of control options.

4.1 Cost Components

Expenditures are differentiated into

- investments,
- fixed operating costs, and
- variable operating costs.

It should be mentioned that the methodology considers some of the parameters as country-specific while others are common for all the countries. Country-specific parameters include, i.a., the average size of installations in a given sector/class, prices for labor and electricity, prices of material inputs as well as the value of recovered 'materials/inputs'. Common parameters include the interest rate and technology-specific data, e.g., lifetime, removal efficiency, investments, maintenance costs, specific demand for labor, energy, specific savings of materials, etc. The methodology considers the application potential of a technology to a given sector by introducing an applicability parameter. For a discussion of the applicability parameter see Section 2.2 in this document.

4.1.1 Investments

Investments include the expenditures accumulated until the start-up of an installation, e.g., delivery of the installation, construction, engineering and consulting, land costs, etc. If there is a size dependency of the unit investments *(I)*, it is taken into account using the function shown in Equation 2. If an existing installation is retrofitted, higher investments can be taken into account through the retrofit cost factor *(r)*.

$$I_{i,j,k} = \left(ci^{f}_{j,k} + \frac{ci^{v}_{j,k}}{s_{i,j}} \right) \times (1 + r) \qquad (2)$$

where:

i,j,k	country, sector, and abatement technology, respectively;
ci^f, ci^v	coefficients of the investment function;
$s_{i,j}$	an average size of the installation in the sector;
r	retrofit factor.

The investment costs are annualized over the technical lifetime *(lt)*, using the interest rate *(q)*.

$$I^{an}{}_{i,j,k} = I_{i,j,k} \times \frac{(1+q)^{lt} \times q}{(1+q)^{lt} - 1} \qquad (3)$$

4.1.2 Fixed Operating Costs

Annual fixed operating costs *(OM^{fix})* include costs of maintenance, taxes and administrative overhead. They are not related to the actual use of the installation. These costs are presented as a fixed percentage *(f)* of the total investments.

$$OM^{fix}{}_{i,j,k} = I_{i,j,k} \times f_{j,k} \qquad (4)$$

where

i,j,k	country, sector, and abatement technology, respectively;
I	investment cost for a given technology;
f	fixed percentage of total investments for technology.

4.1.3 Variable Operating Costs

Variable operating costs *(OM^{var})* are related to the operation of the installation and may include the following elements:

- additional labor demand,
- electricity use,
- additional fuel demand (e.g. gas, oil…),
- saving of solvents, gasoline, etc.,
- other.

In the model some of the parameters (e.g., labor demand, fuel demand) are related to the input and other (e.g., savings of gasoline or solvents) to the removed VOC. Any savings, either lower labor demand or solvent saved, are associated with a negative sign.

To estimate variable operating costs, country specific prices *(p)* are taken into account, see Equation 5.

$$OM^{\mathrm{var}}{}_{i,j,k} = \sum_{r=1}^{n} \left(E_{k,r} \times p_{i,j,k,r} \right) \qquad (5)$$

where

i,j,k,r	country, sector, abatement technology, and parameters related to the operation of the installation (see above), respectively;
E	listed above parameters specific for the considered process;
p	country-specific price for *(E)* parameter of operating costs.

4.2 Constructing a Cost Curve

With the investments, the fixed and the variable operating cost calculated as described above, for a given technology *(k)* in sector *(j)* total annual costs *($C_{i,j,k}$)* could be derived:

$$C_{i,j,k} = I^{an}_{i,j,k} + OM^{fix}_{i,j,k} + OM^{\mathrm{var}}_{i,j,k} \qquad (6)$$

with

i,j,k	country, sector, and abatement technology, respectively;
I^{an}	annualized investment costs;
OM^{fix}	fixed operating costs;
OM^{var}	variable operating costs.

The unit costs *(Uc)* of a control option are calculated using its removal efficiency (Equation 7). They are expressed in ECU/ton of VOC removed.

$$Uc_{i,j,k} = \frac{C_{i,j,k}}{ef_{i,j} \times \eta_{i,j,k} \times \alpha_{i,j,k}} \qquad (7)$$

where:

i,j,k	country, sector, and abatement technology, respectively;
C	total annual cost;
ef	unabated emission factor;
η	removal efficiency of the abatement option;
α	applicability of a given option.

Based on these unit cost, a cost curve is constructed first for every sector and then for the whole region (country), employing the principle that technologies with higher costs and lower reduction efficiency are considered not cost-efficient and are excluded from further analysis. Marginal costs *(Mc),* i.e., the costs of removing an additional unit of VOC by a given control technology, are calculated for each sector *(j)* along Equation 8. Finally, the remaining (cost-efficient) abatement options are ordered according to increasing marginal costs and thus form the cost curve for the considered region *(i)*.

$$Mc_k = \frac{Uc_k \delta_k - Uc_{k-1}\delta_{k-1}}{\delta_k - \delta_{k-1}} \qquad (8)$$

where:

k	abatement technology in sector *(j)* and country *(i)*;
Uc	unit cost (see Equation 7);
δ	'effective' removal efficiency of considered option *(k)* that takes into account the applicability factor, i.e., $\delta = \eta * \alpha$, where η is the removal efficiency and α its applicability in a given sector and country.

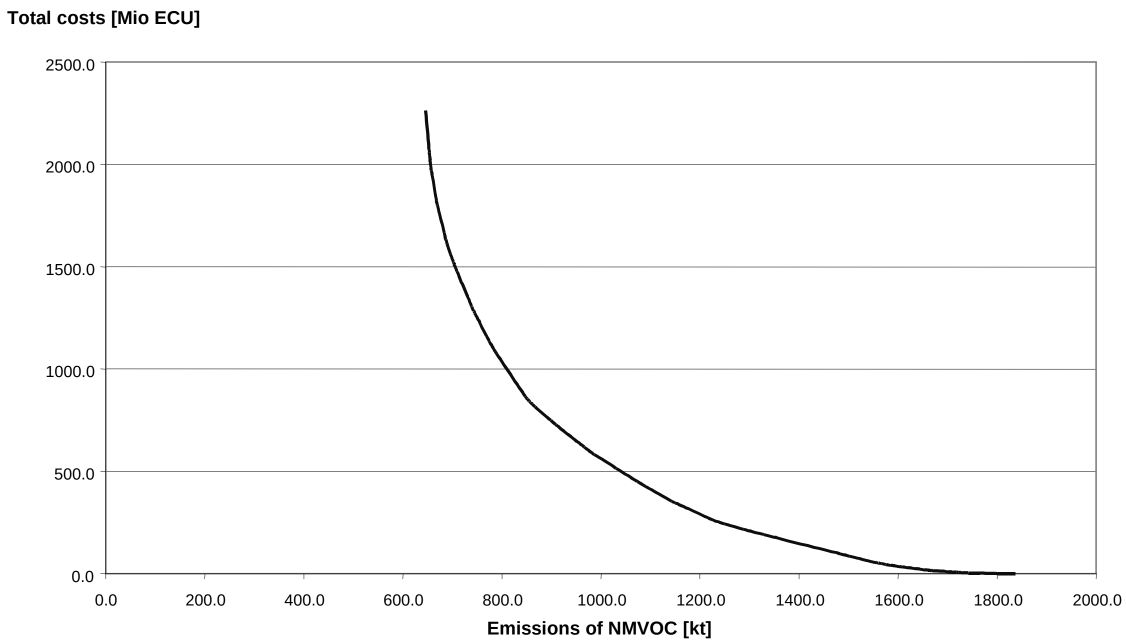
An example cost curve is presented in Table 8 and Figure 2. The first row in Table 8 shows initial emissions for a given year and in a given country. The codes of sectors and control technologies are explained in Annex 2. The amount of VOC reduced by a particular technology can be derived comparing emissions given for this option in column *"Remaining emissions"* with the preceding value. The *"Total cost"* column displays cumulative costs. This means that for any emission level a cost value in this column represents total costs incurred to achieve this level of emissions. The example presented in Table 8 contains only a part of a cost curve, which typically includes some 60 to 80 control options ordered according to increasing marginal costs.

A graphical interpretation of Table 8 is presented in Figure 2. Remaining emissions of VOC are on the x-axis and the total cost on the y-axis. The highest emission value is called the initial emissions and the lowest level is often referred to as maximum feasible reduction (MFR). Often in literature a cost curve is presented in different ways where instead of remaining emissions, the amount of pollutant reduced is shown on the x-axis.

Table 8: Example of a VOC cost curve

Sector code	Control technology	Marginal cost [ECU/t VOC]	Remining emissions [kt]	Total cost [Mio ECU]
			1840.5	
PIS	REF	10	1836.6	0.04
GLUE	HSE	10	1829.3	0.11
PRINT_NEW	HSE	10	1828.1	0.12
PRINT	HSE	10	1827.7	0.13
REF_PROC	LK_I	12	1802.2	0.44
PRINT_NEW	WBI	59	1796.7	0.76
AGR_BURN	BAN	60	1765.0	2.67
IND_OTH	HSE	60	1758.7	3.05
IND_P	HAM	66	1742.5	4.12
PRINT	WBI	67	1741.6	4.17
D_REFDEP	IFC	129	1722.8	6.60
DEGR	BEMT	144	1718.8	7.17
EXD_LQ_NEW	VBAL	169	1667.8	15.78
REF_PROC	LK_I+COWS	211	1662.0	17.02
PRINT	WBI+HSE+ACA	233	1660.4	17.38
D_GASST	ST_IB	312	1607.0	34.06
…	…	…	…	…

Figure 2: Example of the VOC cost curve for stationary sources



4.3 Summary of Abatement Costs for the Major Control Options

Since the RAINS model includes data for nearly forty countries in Europe and there is a great variety in values of parameters used to derive costs for these countries, Table 9 can only present a summary with typical cost ranges for the major control option. The data sets containing detailed information for every region/country is available at the RAINS web site (http://www.iiasa.ac.at/~rains/databases.html).

Table 9: Typical unit abatement costs of the major categories of VOC abatement measures for the source categories distinguished in the RAINS-VOC module

Sector	Technology	Unit cost range [ECU/t VOC]
	Solvent use	
Dry Cleaning	Good housekeeping and adsorption Closed circuit conventional or new machines	600-1300 $0.5\text{-}3/1.2\text{-}4.5*10^3$
Degreasing operations	Basic emission management techniques Carbon adsorption Low temperature plasma process Conveyored degreaser with integrated adsorption Water based systems	< 150 1300-2200 1000-4700 1700-2400 1800-4100
Domestic solvent use	Substitution	~ 4300
Non-industrial paint use	Emulsions/ dispersion paints Water based paints High solids	~ 0 400-800 1000-4000
Industrial paint use /car manufacturing	Good housekeeping, application technique modification Process modification and substitution Adsorption, incineration	< 200 $0.6\text{-}0.9/1\text{-}6.5*10^3$ $1.5\text{-}2.1/1.3\text{-}9*10^3$
Vehicle refinishing	Good housekeeping, application technique modification Housekeeping, application technique, substitution /new inst.	≤ 0 < 1000/~3000
Products incorporating solvents	Reformulation Basic emission management and end-of-pipe	< 20 300-1200
Products not incorporating solvents	Solvent management plan and substitution End-of-pipe (adsorption, incineration)	~ 200 1200-2500
Pharmaceutical industry	Good housekeeping and end-of-pipe	2500-6000
Printing		
Packaging	Low solvent inks and enclosure Water based inks / (new installations) Enclosure and adsorption Enclosure and incineration	20-30 30-50/100-300 150-300 1150-1650
Publishing	Low solvent inks and enclosure Water based inks / (new installations) Enclosure and adsorption	20-50 30-70/350-750 1000-2000
Screen printing	Water based inks Enclosure and incineration Water based inks and biofiltration	500-600 8700-9700 750-850
Offset	Primary measures 'Solvent free' inks and solvent management plan Enclosure and incineration	< 20 ~ 0 1100
Glues and adhesives in industry	Good housekeeping Substitution Incineration	< 20 ~ 350 ~ 600

Sector	Technology	Unit cost range [ECU/t VOC]
Preservation of wood	Double vacuum impregnation & dryer enclosure As above plus end-of-pipe	~ 2800 3800-7400
Other industrial use of solvents	Process modification and biofiltration Water based coating (leather tanning) New agrochemical products	~ 600 ~ 350 ~ 0
Chemical industry		
Organic chemical industry, processing and storage	Quarterly / monthly inspection and maintenance programs Flaring Incineration Internal floating covers and secondary seals Vapor recovery units	~ 1600 / ~ 5800 ~ 350 ~ 800 ~ 2800 5600-6200
Liquid fuel extraction, processing and distribution		
Fuel extraction, loading and transport	Venting alternatives and increased recovery Improved ignition system on flares Vapor balancing on tankers and loading facilities	1800-2200 4500-5600 40-300
Refineries	Quarterly/ monthly inspection and maintenance programs Covers on oil/water separators Flaring / Incineration Internal floating covers and secondary seals Vapor recovery units (Stage IA) - single/double stage systems	< 100/300-1300 200-400 200-300 < 100 $0.7\text{-}2.9/0.8\text{-}3.3*10^3$
Fuel storage and distribution	Internal floating covers and secondary seals Vapor recovery units (Stage IA) - single/double stage systems Stage II Stage IB	< 100 $0.7\text{-}2.9/0.8\text{-}3.3*10^3$ 1500-3300 300-800
Transport and combustion		
Gasoline evaporation	Small carbon canister	50-600
2-stroke engines	Oxidation catalyst	900
Residential combustion	New boilers (fuelwood) New boilers (other solid fuel) Catalyst (fuelwood) Catalyst (other solid fuel)	100-300 100-800 1700-5000 1800-10000
Miscellaneous		
Food and drink industry	End-of-pipe	10000
Agriculture	Ban on burning waste	60
Other industrial	Good housekeeping Bitumen substitution	< 100 < 20
Waste disposal	Improved landfills	400

5 References

AAMA (American Automobile Manufacturers Association) (1997) *World Motor Vehicle Data - 1997 Edition*. AAMA, Washington, 1997.

Adler, P. (1993) *Reductions of VOC emissions from painting of car bodies in the Swedish car industry.* Swedish Environmental Protection Agency, November 1993.

Allemand, N., R. Bouscaren, D. Heslinga, I. Marlowe, C.J. Potter, M. Woodfield, K. H. Zierock (1990) *A Costed Evaluation of Options for the Reduction of Photochemical Oxidant Precursors, Volume 2. - Abatement Technology and Associated Costs.* Report No. EUR 12537/II EN, Commission of the European Communities, Brussels - Luxembourg.

Bouscaren, R., N. Allemand, W. F. J. M. Engelhard, S. C. Wallin, K.-H. Zierock (1988) *Volatile Organic Compounds and Nitrogen Oxides - Cost Effectiveness of Measures Designed to Reduce the Emissions of Precursors of Photochemical Oxidants, Phase 1 - Final Report*. Commission of the European Communities, Report No. EUR 11856 EN, May 1988.

Breihofer, D., Mielenz, Rentz, O. (1991) *Emission Control of SO2, NOx and VOC at Stationary Sources in the Federal Republic of Germany*. Institute of Industrial Production, University of Karlsruhe. Karlsruhe, May 1991.

BUWAL (Bundesamt für Umwelt, Wald und Landschaft) (1993*) Handbuch - für die Kontrolle von Tankstellen mit Gasrückführung*. Ausgabe 1993. BUWAL, Bern, Switzerland, 1993 [in German].

BUWAL (Bundesamt für Umwelt, Wald und Landschaft) (1995*) Handbuch - Emissiondfaktoren für stationäre Quellen*. Ausgabe 1995. BUWAL, Bern, Switzerland, 1995 [in German].

Capros, P., Manztos L., Kokkolakis E. and Antoniou Y. (1997) *Business as usual scenario for the EU Energy System 1995-2020.* Final Report to European Commission, DG-XVII/A2. National Technical University of Athens.

Chem Systems (1996) *Further Research into Costs of the Proposed Stage II Controls and On-board Vapour Recovery*. A report prepared for the Department of the Environment. London, March 1996.

CITEPA (Centre Interprofessionnel Technique D'etudes de la Pollution Atmospherique) (1994) *CORINAIR France 1990, Estimation des Emissions de Pollutants Atmospheriques* - rapport final. CITEPA, Paris, June 1994 [in French].

Cofala J., Kurz R., Amann M. (1997) *Application of the Current EU Air Emissions Standards to the Central and Eastern European Countries - An Integrated Assessment of the Environmental Effects*. Draft Final Report to the European Environmental Agency (EEA). IIASA, Laxenburg, Austria, July 1997

Cofala, J. and Syri, S. (1998) *Nitrogen Oxides Emissions, Abatement Technologies and Related Costs for Europe in the RAINS Model Database*. IIASA Interim Report, IR-98-88. Laxenburg, Austria

Cofala, J. and Syri, S. (1998) *Sulfur Dioxide Emissions, Abatement Technologies and Related Costs for Europe in the RAINS Model Database*. IIASA Interim Report, IR-98-89. Laxenburg, Austria

CONCAWE (1988) *The control of vehicle evaporative and refuelling emissions - the "on-board" system.* Report no. 88/62. The Hague, November 1988.

CONCAWE (1990) *Closing the Gasoline System - Control of Gasoline Emissions from the Distribution System and Vehicles*. Report No. 3/90, CONCAWE, Brussels.

DFIU (Deutsch-Französisches Institut für Umweltforschung) (1996) *Proceedings of the Workshop on VOC Abatement Options and their Costs for Use in Integrated Assessment Modeling.* October 28-30, 1996, Karlsruhe, Germany.

EC (European Commission DG-XI) (1994*) CORINAIR - Technical annexes, Volume 2 - Default emission factors handbook*. EUR 12586/2 EN, Brussels-Luxembourg

EEC (Economic Commission for Europe VOC Task Force) (1990) *Emissions of Volatile Organic Compounds (VOC) from Stationary Sources and Possibilities of their Control.* Karlsruhe, July 1990.

EEA (European Environmental Agency) (1996) *Joint EMEP/CORINAIR Atmpospheric Emission Inventory Guidebook, First Edition.* Copenhagen, 1996

EPA (U.S. Environmental Protection Agency) (1992) *Control of VOC Emissions from Ink and Paint Manufacturing Processes.* EPA-450/3-92-013, April 1992.

EPA (U.S. Environmental Protection Agency) (1994) *Control Techniques for Volatile Organic Compound Emissions from Stationary Sources.* Government Institutes, Inc., Rockville, Maryland, January 1994.

ERM Economics (1996) *Costs and Benefits of the Reduction of VOC Emissions from Industry*. ERM Economics, CHEM Systems, London, May 1996

FAO (1997) *Forest products yearbook 1995.* FAO Forestry Series No. 30. FAO Statistics Series No. 137. Rome.

Foster, F. O., R. H. Lilie, W. G. Roberts, G. A. van Ophem (1987) *Cost-Effectiveness of Hydrocarbon Emission Controls in Refineries from Crude Oil Receipt to Product Dispatch*. Report No. 87/52, CONCAWE, Den Haag, January 1987.

Giddings, T.J., Marlowe, I.T., Richardson, S.J. (1991) *Reduction of Volatile Organic Compound Emissions from Industrial Coating and Impregnation of Wooden Surfaces.* Final report to the Commission of the European Communities. Report No: IR 313 (PA), 28 November, 1991.

Giddings, T.J., Marlowe, I.T., Richardson, S.J., Macdonald, E.K., Okeke, O. (1994) *Reduction of Volatile Organic Compound Emissions from Industrial Coating of Metallic Surfaces Using Carbon Based Materials.* Final report to the Commission of the European Communities. Report No: IR 323 (PA), 2 October 1991. Brussels-Luxembourg, 1994.

Hein, J., Kippeln, C, Schultmannn, F., Rentz, O. (1994) *Assessment of the cost involved with the Commission's draft proposal for a Directive on the limitation of the organic solvent emissions from the industrial sectors.* Final Report: Appendix. Karlsruhe, August 1994.

Heslinga, D.C. (1990) *Emission reduction of volatile organic compounds in the metal cleaning and degreasing sector.* Final report 90-361, TNO Division of Technology for Society, Apeldoorn, The Netherlands, December 1990.

IEA (International Energy Agency) (1993) *Energy Prices and Taxes - Fourth Quarter 1992*. OECD/IEA, Paris 1993.

IFARE (French-German Institute for Environmental Research) (1998) *Task Force on the Assessment of Abatement Options/Techniques for Volatile Organic Compounds from Stationary Sources (Part 1 and 2).* Draft BAT background document. University of Karlsruhe, Germany, April 2, 1998

IMF (International Monetary Fund) (1995) *International Financial Statistics Yearbook 1995*. Vol. XLVIII, Washington, 1995.

IRF (International Road Federation) (1993) *World Road Statistics 1988-1992 - Edition 1993*. IRF, Geneva, Switzerland, November 1993.

Jourdan, M., Rentz, O. (1991) *Reduction of Volatile Organic Compunds from Dry Cleaning Facilities*. Reprt to the CEC, DG XI. Final Report, Karlsruhe, November 1991.

Klaassen, G. (1991) *Costs of Controlling Ammonia Emissions in Europe.* Status Report (SR-91-02), International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria, April 1991.

KWS 2000 (1989) *Control Strategy for Emissions of Volatile Organic Compounds.* Project Group Hydrocarbons 2000. Ministry of Housing, Physical Planning and Environment. The Hague, February 1989

KWS 2000 (1993) *Strategie 1992-2000.* Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer. [in Dutch]

KWS 2000 (1997) *Annual Report 1995*. InfoMil, Den Haag, March 1997

McArragher, J. S. et. al (1987*) An Investigation Into Evaporative Hydrocarbon Emissions from European Vehicles*. Report No. 87/60, CONCAWE, The Hague.

McGettigan, M. F. (1993): *CORINAIR 1990 Emission Inventory for Ireland* - Final Report. Environmental Research Unit, Department of the Environment. Dublin, July 1993.

Ministry of Public Works, Transport and the Environment, Secretary of State for Environment and Housing, Directorate-General for Environmental Policy (1995) *CORINAIR Spain 1990 - Inventory of Emission of Pollutants into the Atmosphere. Volume 2: Analysis by SNAP Emitting Activities.* Analysis Estadistico de Datos, S.A., Madrid, July 1995.

Ministry of Public Works, Transport and the Environment, Secretary of State for Environment and Housing, Directorate-General for Environmental Policy (1996)

CORINAIR Spain 1991, 1992, 1993 (and revision of 1990) - Inventory of Emission of Pollutants into the Atmosphere. Volume 1: Approach, General Methodology and Synthesis of Results. Volume 2: Analysis by SNAP Emitting Activities. Analysis Estadistico de Datos, S.A., Madrid, October 1996.

MVMA (Motor Vehicle Manufacturers Association of the United States, Inc.) (1992) *World Motor Vehicle Data* - 1992 Edition. Washington, 1992.

NUTEK (Swedish National Board for Industrial and Technical Development) (1997) *Environmentally-Adapted Local Energy Systems*. Report No. B 1997:5. NUTEK, Stockholm, Sweden.

OECD (Organization for Economic Co-operation and Development) (1990) *Emissions of Volatile Organic Compounds from Solvents Usage Operations*. Environment monographs No. 23. Paris, August 1990

OECD (Organization for Economic Co-operation and Development) (1992) *Emission Control for Nitrogen Oxides and Volatile Organic Compounds - Technology and Costs Compendium*. Environment monographs No. 22. Paris, January, 1992

OECD (Organization for Economic Co-operation and Development) (1995) *Motor Vehicle Pollution. Reduction strategies beyond 2010.* OECD, Paris, France

Oonk, J., Jol, A. (1995) *Cost-effectiveness of environmental measures in industry - Extended summary.* TNO-MEP-R95/335, TNO Institute of Environmental Sciences, Energy Research and Process Innovation. Appledoorn, Netherlands, 23 October 1995.

Passant, N. R. (1993) *Emissions of Volatile Organic Compounds from Stationary Sources in the UK*. Warren Spring Laboratory LR990. Stevenage, UK, December 1993

Passant, N. R. and Vincent, K. (1998) *Review of the Efficiency and Cost of Control Measures for Sulphur Dioxide and Volatile Organic Compounds.* Draft final report AEAT-3851. AEA Technology, Culham, United Kingdom, July 1998

Rentz O., Röll C., Oertel D., Holtman T., Hein J., Karl U. (1993) *Minderung der VOC-Emissionen in der Bundesrepublik Deutschland.* UBA-FB 104 04 167, May 1993. [in German]

Schürmann (1994) *Study on the Detailed Methodology of the Determination of VOC-Emissions in Gasoline Distribution (DRAFT)*. Weyer Verfahrenstechnik, Basel, Switzerland. December 19, 1994. Study on request of Federal Office of Environment, Forests and Landscape, Section Air Pollution Control, Bern, Switzerland.

SHI (Slovak Hydrometeorological Institute) (1994*) CORINAIR 90 - Emissions Inventory for Slovakia* - final report. SHI, Bratislava, 1994.

Umweltministerium Baden-Württemberg (1993) *Konzeption zur Minderung der VOC-Emissionen in Baden-Württemberg - Bericht der VOC-Landeskommission.* Luft, Boden, Abfall - Heft 21. Karlsruhe, January 1993 [in German].

VROM (Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer) (1995) *Emission Reduction by Internal Floating Roofs.* Projectbureau KWS 2000. May 1995

VROM/DGM (Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer - Directoraat-General Milieubeheer) (1995) *Kosteneffectiviteit van milieumaatregelen in de industrie - beschrijving van de methodiek, deel A.* No. 119. VROM, Den Haag, December 1995. [in Dutch]

VROM/DGM (Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer - Directoraat-General Milieubeheer) (1997) *Vervolgonderzoek Kosteneffectiviteit van Milieumaatregelen in de Industrie - Eindrapportage.* VROM, Den Haag, March 1997. [in Dutch]

Wenborn, M. J., Marlowe, I.T., Woodfield, M.J., Passant, N. R., Richardson, S.J., Emmott, M.A., Warren, R.F., Leggett, S.M., ApSimon, H.M., Smith, S. (1995) *VOC Emissions in Europe: An Assessment of the Potential for Abatement and an Estimate of the Associated Costs.* AEA/CS/20011001/REMA-167/Issue 1. AEA Technology, November 1995.

Williams, L. J., D. Beardshall, P. G. Edgington, F.O. Foster, R.H. Lilie, H.D. Richards (1986): *Hydrocarbon Emissions from Gasoline Storage and Distribution Systems*. Report No. 85/54, CONCAWE, DenHaag, September 1986.

6 ANNEX 1

Relation between SNAP nomenclature used in CORINAIR’90 and RAINS model for NMVOC

TRARD Road Transport

TRARD CAR LDV Light Duty Trucks

7	2	0	ROAD TRANSPORT - LIGHT DUTY VEHICLES < 3.5 t
7	2	1	ROAD TRANSPORT - LIGHT DUTY VEHICLES < 3.5 t : HIGHWAY DRIV.
7	2	2	ROAD TRANSPORT - LIGHT DUTY VEHICLES < 3.5 t : RURAL DRIVING
7	2	3	ROAD TRANSPORT - LIGHT DUTY VEHICLES < 3.5 t : URBAN DRIVING

TRARD CAR PASS Passenger Cars

7	1	0	ROAD TRANSPORT - PASSENGER CARS
7	1	1	ROAD TRANSPORT - PASSENGER CARS : HIGHWAY DRIVING
7	1	2	ROAD TRANSPORT - PASSENGER CARS : RURAL DRIVING
7	1	3	ROAD TRANSPORT - PASSENGER CARS : URBAN DRIVING

TRARD EVAP Gasoline Evaporation

7	6	0	ROAD TRANSPORT - GASOLINE EVAPORATION FROM VEHICLES

TRARD HDT Trucks and Busses

7	3	0	ROAD TRANSPORT - HEAVY DUTY VEHICLES > 3.5 t AND BUSES
7	3	1	ROAD TRANS. - HEAVY DUTY VEHIC. AND BUSES : HIGHWAY DRIVING
7	3	2	ROAD TRANS. - HEAVY DUTY VEHIC. AND BUSES : RURAL DRIVING
7	3	3	ROAD TRANS. - HEAVY DUTY VEHIC. AND BUSES : URBAN DRIVING

TRARD MBIKE Motorcycles and Mopeds

7	4	0	ROAD TRANSPORT - MOPEDS AND MOTORCYCLES < 50 CM3
7	5	0	ROAD TRANSPORT - MOTORCYCLES > 50 CM3
7	5	1	ROAD TRANSPORT - MOTORCYCLES > 50 CM3 : HIGHWAY DRIVING
7	5	2	ROAD TRANSPORT - MOTORCYCLES > 50 CM3 : ROAD DRIVING
7	5	3	ROAD TRANSPORT - MOTORCYCLES > 50 CM3 : URBAN DRIVING

TROTH Other Transport

TROTH AIR Air Transport (LTO only)

8	5	0	OTHER MOB. SOURCES - AIRPORTS (LTO cycles and ground act.)

TROTH OFF Off-Road Vehicles

8	1	0	OTHER MOB. SOURCES - OFF ROAD VEHICLES AND MACHINES
8	1	1	OTHER MOB. SOURCES - OFF ROAD VEHIC. AND MACHINES: AGRICULT.
8	1	2	OTHER MOB. SOURCES - OFF ROAD VEHIC. AND MACHINES: FORESTRY
8	1	3	OTHER MOB. SOURCES - OFF ROAD VEHIC. AND MACHINES: INDUSTRY
8	1	4	OTHER MOB. SOURCES - OFF ROAD VEHIC. AND MACHINES: MILITARY
8	1	5	OTHER MOB. SOURCES - HOUSEHOLD / GARDENING
8	2	0	OTHER MOB. SOURCES - RAILWAYS

TROTH SHIP Ships

8	3	0	OTHER MOB. SOURCES - INLAND WATERWAYS
8	4	0	OTHER MOB. SOURCES - MARINE ACTIVITIES
8	4	1	OTHER MOB. SOURCES - MARINE ACTIVITIES: HARBOURS
8	4	2	OTHER MOB. SOURCES - MARINE ACTIVITIES: NATIONAL SEA TRAFFIC
8	4	3	OTHER MOB. SOURCES - MARINE ACTIVITIES: NATIONAL FISHING

SOLV Solvent Use

SOLV CHEM **Solvent Use in Chemical Industry**

6	3	0	SOLVENT USE - CHEMICALS PRODUCTS MANUFACTURING OR PROCESSING

SOLV CHEM PHARM **Pharmaceutical Industry**

6	3	6	SOLVENT USE - CHEMICAL PRODUCTS : PHARMACEUTICAL PROD. MANU.

SOLV CHEM PIS **Products Incorporating Solvents**

6	3	10	SOLVENT USE - CHEMICAL PRODUCTS : ASPHALT BLOWING
6	3	11	SOLVENT USE - CHEMICAL PRODUCTS : ADHESIVE TAPES MANUFACT.
6	3	7	SOLVENT USE - CHEMICAL PRODUCTS : PAINTS MANUFACTURING
6	3	8	SOLVENT USE - CHEMICAL PRODUCTS : INKS MANUFACTURING
6	3	9	SOLVENT USE - CHEMICAL PRODUCTS : GLUES MANUFACTURING

SOLV CHEM PNIS **Products not Incorporating Solvents**

6	3	1	SOLVENT USE - CHEMICAL PRODUCTS : POLYESTER PROCESSING
6	3	2	SOLVENT USE - CHEMICAL PRODUCTS : POLYVINYLCHLORIDE PROCESS.
6	3	3	SOLVENT USE - CHEMICAL PRODUCTS : POLYURETHANE PROCESSING
6	3	4	SOLVENT USE - CHEMICAL PRODUCTS : POLYSTYRENE FOAM PROCESS.
6	3	5	SOLVENT USE - CHEMICAL PRODUCTS : RUBBER PROCESSING

SOLV CLEAN **Surface Cleaning**

6	2	0	SOLVENT USE - DEGREASING AND DRY CLEANING

SOLV CLEAN DEGR **Metal Degreasing**

6	2	1	SOLVENT USE - METAL DEGREASING

SOLV CLEAN DRY **Dry Cleaning**

6	2	2	SOLVENT USE - DRY CLEANING

SOLV OTHER DOM **Domestic Solvent Use (other than paint)**

6	4	8	SOLVENT USE - DOMESTIC SOLVENT USE (other than paint appl.)

SOLV OTHER GLUE **Application of Glues, Ahesives in Industry**

6	4	5	SOLVENT USE - APPLICATION OF GLUES AND ADHESIVES

SOLV OTHER IND **Other Use of Solvents in Industry**

6	4	0	SOLVENT USE - OTHER USE OF SOLVENTS AND RELATED ACTIVITIES
6	4	1	SOLVENT USE - GLASS WOOL ENDUCTION
6	4	2	SOLVENT USE - MINERAL WOOL ENDUCTION
6	4	4	SOLVENT USE - FAT EDIBLE AND NON EDIBLE OIL EXTRACTION

SOLV OTHER VEHTR **Treatment of Vehicles**

6	4	7	SOLVENT USE - UNDERSEAL TREATMENT OF VEHICLES
6	4	9	SOLVENT USE - VEHICLES DEWAXING

SOLV OTHER WOOD **Preservation of Wood**

6	4	6	SOLVENT USE - PRESERVATION OF WOOD

SOLV PAINT **Paint Application**

6	1	0	SOLVENT USE - PAINT APPLICATION

SOLV Solvent Use

SOLV PAINT ARCH Architectural painting

6	1	3	SOLVENT USE - PAINT APPLICATION : CONSTRUCTION AND BUILDINGS

SOLV PAINT AUTO Manufacture of Automobiles

6	1	1	SOLVENT USE - PAINT APPLICATION : MANUFACTURE OF AUTOMOBILES

SOLV PAINT DOM Domestic Use

6	1	4	SOLVENT USE - PAINT APPLICATION : DOMESTIC USE

SOLV PAINT IND Industrial Use

6	1	2	SOLVENT USE - PAINT APPLICATION : OTHER INDUS. APPLICATION

SOLV PRINT Printing Industry

6	4	3	SOLVENT USE - PRINTING INDUSTRY

CHEM Chemical Industry

CHEM INORG Inorganic Chemical Industry

4	4	0	PRODUCTION PROC. - INORGANIC CHEMICAL INDUSTRY
4	4	1	PRODUCTION PROC. - SULFURIC ACID
4	4	2	PRODUCTION PROC. - NITRIC ACID
4	4	3	PRODUCTION PROC. - AMMONIA
4	4	4	PRODUCTION PROC. - AMMONIUM SULPHATE
4	4	7	PRODUCTION PROC. - NPK FERTILISERS
4	4	8	PRODUCTION PROC. - UREA
4	4	9	PRODUCTION PROC. - CARBON BLACK

CHEM ORGAN Organic Chemical Industry - Processing and Storage

4	5	0	PRODUCTION PROC. - ORGANIC CHEMICAL INDUSTRY

CHEM ORGANPROC Organic Chemical Industry - Processing

4	5	1	PRODUCTION PROC. - ETHYLENE
4	5	10	PRODUCTION PROC. - STYRENE
4	5	11	PRODUCTION PROC. - POLYSTYRENE
4	5	12	PRODUCTION PROC. - STYRENE BUTADIENE
4	5	13	PRODUCTION PROC. - STYRENE-BUTADIENE LATEX
4	5	14	PRODUCTION PROC. - STYRENE-BUTADIENE RUBBER (SBR)
4	5	15	PRODUCTION PROC. - ACRYLONIT. BUTADIENE STYRENE (ABS) RESINS
4	5	16	PRODUCTION PROC. - ETHYLENE OXYDE
4	5	17	PRODUCTION PROC. - FORMALDEHYDE
4	5	18	PRODUCTION PROC. - ETHYLBENZENE
4	5	19	PRODUCTION PROC. - PHTALIC ANHYDRIDE
4	5	2	PRODUCTION PROC. - PROPYLENE
4	5	20	PRODUCTION PROC. - ACRYLONITRILE
4	5	21	PRODUCTION PROC. - ADIPIC ACID
4	5	3	PRODUCTION PROC. - 1,2 DICHLOROETHANE (except 040505)
4	5	4	PRODUCTION PROC. - VINYLCHLORIDE (except 040505)
4	5	5	PRODUCTION PROC. - 1,2 DICHLOROETH.+VINYLCHL.(balanced proc)
4	5	6	PRODUCTION PROC. - POLYETHYLENE LOW DENSITY
4	5	7	PRODUCTION PROC. - POLYETHYLENE HIGH DENSITY
4	5	8	PRODUCTION PROC. - POLYVINYLCHLORIDE
4	5	9	PRODUCTION PROC. - POLYPROPYLENE

CHEM Chemical Industry

CHEM ORGANSTORE Storage and Handling of Chemical Products

4	*5*	*22*	*PRODUCTION PROC. - STORAGE AND HANDLING OF CHEMICAL PRODUCTS*

REF Refineries

REF Refineries

4	*1*	*0*	*PRODUCTION PROCESSES - PETROLEUM INDUSTRIES*

REF PROC Refineries - Process

4	*1*	*1*	*PRODUCTION PROC. - PETROLEUM PRODUCTS PROCESSING*
4	*1*	*2*	*PRODUCTION PROC. - FLUID CATALYTIC CRACKING - CO BOILER*
4	*1*	*3*	*PRODUCTION PROC. - SULPHUR RECOVERY PLANTS*

GDIST Gasoline Distribution

GDIST Gasoline Distribution

5	*5*	*0*	*GASOLINE DISTRIBUTION*

GDIST GASST Service Stations

5	*5*	*3*	*GASOLINE DISTRIBUTION - SERVICE STATIONS (incl. refuelling)*

GDIST REFDP Refinery (storage), Transport, Depots

4	*1*	*4*	*PRODUCTION PROC. - STORAGE & HANDL. OF PRODUCTS IN REFINERY*
5	*5*	*1*	*GASOLINE DISTRIBUTION - REFINERY DISPATCH STATION*
5	*5*	*2*	*GASOLINE DISTRIB. - TRANSP. AND DEPOTS (exc. serv. station)*

COMB Stationary Combustion

COMB IND Industrial Combustion

3	*1*	*0*	*INDUS. COMBUS. IN BOILERS, GAS TURBINES AND STATION. ENGINES*
3	*1*	*1*	*INDUSTRIAL COMBUSTION - PLANTS = 300 MW*
3	*1*	*2*	*INDUSTRIAL COMBUSTION - PLANTS = 50 MW AND < 300 MW*
3	*1*	*3*	*INDUSTRIAL COMBUSTION - PLANTS < 50 MW*
3	*1*	*4*	*INDUSTRIAL COMBUSTION - GAS TURBINES*
3	*1*	*5*	*INDUSTRIAL COMBUSTION - STATIONARY ENGINES*
3	*2*	*0*	*INDUSTRIAL COMBUSTION - PROCESS FURNACES WITHOUT CONTACT*
3	*2*	*1*	*INDUSTRIAL COMBUSTION - REFINERY PROCESSES FURNACES*
3	*2*	*2*	*INDUSTRIAL COMBUSTION - COKE OVEN FURNACES*
3	*2*	*3*	*INDUSTRIAL COMBUSTION - BLAST FURNACES COWPERS*
3	*2*	*4*	*INDUSTRIAL COMBUSTION - PLASTER FURNACES*
3	*3*	*0*	*INDUSTRIAL COMBUSTION - PROCESSES WITH CONTACT*
3	*3*	*1*	*INDUSTRIAL COMBUSTION - SINTER PLANT*
3	*3*	*10*	*INDUSTRIAL COMBUSTION - SECONDARY ALUMINIUM PRODUCTION*
3	*3*	*11*	*INDUSTRIAL COMBUSTION - CEMENT*
3	*3*	*12*	*INDUSTRIAL COMBUSTION - LIME*
3	*3*	*13*	*INDUSTRIAL COMBUSTION - ASPHALT CONCRETE PLANTS*
3	*3*	*14*	*INDUSTRIAL COMBUSTION - FLAT GLASS*
3	*3*	*15*	*INDUSTRIAL COMBUSTION - CONTAINER GLASS*
3	*3*	*16*	*INDUSTRIAL COMBUSTION - GLASS WOOL*
3	*3*	*17*	*INDUSTRIAL COMBUSTION - OTHER GLASS*
3	*3*	*18*	*INDUSTRIAL COMBUSTION - MINERAL WOOL*
3	*3*	*19*	*INDUSTRIAL COMBUSTION - BRICKS AND TILES*

RAINS 7 - CORINAIR '90 sectors relation (VOC Emission Module)

COMB Stationary Combustion

COMB IND Industrial Combustion

3	3	2	INDUSTRIAL COMBUSTION - REHEATING FURNACES STEEL AND IRON
3	3	20	INDUSTRIAL COMBUSTION - FINE CERAMICS MATERIALS
3	3	21	INDUSTRIAL COMBUSTION - PAPER MILL INDUSTRY (DRYING PROCES.)
3	3	22	INDUSTRIAL COMBUSTION - ALUMINA PRODUCTION
3	3	23	INDUSTRIAL COMBUSTION - MAGNESIUM (DOLOMITE TREATMENT)
3	3	3	INDUSTRIAL COMBUSTION - GRAY IRON FOUNDRIES
3	3	4	INDUSTRIAL COMBUSTION - PRIMARY LEAD PRODUCTION
3	3	5	INDUSTRIAL COMBUSTION - PRIMARY ZINC PRODUCTION
3	3	6	INDUSTRIAL COMBUSTION - PRIMARY COPPER PRODUCTION
3	3	7	INDUSTRIAL COMBUSTION - SECONDARY LEAD PRODUCTION
3	3	8	INDUSTRIAL COMBUSTION - SECONDARY ZINC PRODUCTION
3	3	9	INDUSTRIAL COMBUSTION - SECONDARY COPPER PRODUCTION

COMB PP Public Power, Cogeneration and District Heating

1	1	0	PUBLIC POWER AND COGENERATION PLANTS
1	1	1	PUBLIC POWER AND COGENERATION - COMBUSTION PLANTS = 300 MW
1	1	2	PUBLIC POWER AND COGENER. - COMBUS. PLANTS = 50 AND < 300 MW
1	1	3	PUBLIC POWER AND COGENERATION - COMBUSTION PLANTS < 50 MW
1	1	4	PUBLIC POWER AND COGENERATION - GAS TURBINES
1	1	5	PUBLIC POWER AND COGENERATION - STATIONARY ENGINES
1	2	0	DISTRICT HEATING PLANTS
1	2	1	DISTRICT HEATING - COMBUSTION PLANTS = 300 MW
1	2	2	DISTRICT HEATING - COMBUSTION PLANTS = 50 MW AND < 300 MW
1	2	3	DISTRICT HEATING - COMBUSTION PLANTS < 50 MW
1	2	4	DISTRICT HEATING - GAS TURBINES
1	2	5	DISTRICT HEATING - STATIONARY ENGINES

COMB RESID Commercial and Residential Combustion

2	0	1	COMMERCIAL, INSTIT. AND RESID. - COMBUSTION PLANTS = 50 MW
2	0	2	COMMERCIAL, INSTIT. AND RESID. - COMBUSTION PLANTS < 50 MW
2	0	3	COMMERCIAL, INSTIT. AND RESID. - GAS TURBINES
2	0	4	COMMERCIAL, INSTIT. AND RESID. - STATIONARY ENGINES

MISC Miscellaneous sources

MISC AGR BURN Stubble Burning and Other Agr. Waste

10	3	0	AGRICULTURE - STUBBLE BURNING
9	7	0	W.T.D. - OPEN BURNING OF AGRICULTURAL WASTES (except 10.03)

MISC FOOD Food and Drink Industry

4	6	5	PRODUCTION PROC. - BREAD
4	6	6	PRODUCTION PROC. - WINE
4	6	7	PRODUCTION PROC. - BEER
4	6	8	PRODUCTION PROC. - SPIRITS

MISC IND Other Industrial Sources

4	2	0	PRODUCTION PROC. - IRON AND STEEL INDUSTRIES AND COLLIERIES
4	2	1	PRODUCTION PROC. - COKE OVEN
4	2	2	PRODUCTION PROC. - BLAST FURNACE CHARGING
4	2	3	PRODUCTION PROC. - PIG IRON TAPPING
4	2	4	PRODUCTION PROC. - SOLID SMOKELESS FUEL
4	2	5	PRODUCTION PROC. - OPEN HEARTH FURNACE STEEL PLANT

MISC Miscellaneous sources

		MISC	IND	Other Industrial Sources
4	2	6		PRODUCTION PROC. - BASIC OXYGEN FURNACE
4	2	7		PRODUCTION PROC. - ELECTRIC FURNACE STEEL PLANT
4	2	8		PRODUCTION PROC. - ROLLING MILLS
4	3	0		PRODUCTION PROC. - NON FERROUS METAL INDUSTRY
4	3	1		PRODUCTION PROC. - ALUMINIUM PRODUCTION (electrolysis)
4	3	2		PRODUCTION PROC. - FERRO ALLOYS
4	3	3		PRODUCTION PROC. - SILICIUM PRODUCTION
4	6	0		PRODUCTION PROC. - WOOD,PAPER PULP,FOOD,DRINK & OTHER IND.
4	6	1		PRODUCTION PROC. - CHIPBOARD
4	6	10		PRODUCTION PROC. - ASPHALT ROOFING MATERIALS
4	6	11		PRODUCTION PROC. - ROAD PAVING WITH ASPHALT
4	6	12		PRODUCTION PROC. - CEMENT
4	6	13		PRODUCTION PROC. - GLASS
4	6	14		PRODUCTION PROC. - LIMES
4	6	2		PRODUCTION PROC. - PAPER PULP (kraft process)
4	6	3		PRODUCTION PROC. - PAPER PULP (acid sulfite process)
4	6	4		PRODUCTION PROC. - PAPER PULP (neutral sulphite semi-chemi.)
4	7	0		PRODUCTION PROC. - COOLING PLANTS

		MISC	WASTE	Waste Treatment and Disposal
9	1	0		WASTE TREATMENT AND DISPOSAL - WASTE WATER TREATMENT
9	2	0		WASTE TREATMENT AND DISPOSAL - WASTE INCINERATION
9	2	1		WASTE TREAT. AND DISP. - INCINER. DOMESTIC/MUNICIPAL WASTES
9	2	2		WASTE TREAT. AND DISP. - INCINERATION OF INDUSTRIAL WASTES
9	2	3		WASTE TREATMENT AND DISPOSAL - FLARING IN OIL INDUSTRY
9	2	4		WASTE TREAT. AND DISP. - FLARING IN CHEMICAL INDUSTRIES
9	2	5		WASTE TREAT. AND DISP. - INCINER. OF SLUDGES FROM WATER TR.
9	3	0		WASTE TREATMENT AND DISPOSAL - SLUDGE SPREADING
9	4	0		WASTE TREATMENT AND DISPOSAL - LAND FILLING
9	6	0		WASTE TREATMENT AND DISPOSAL - BIOGAS PRODUCTION

NAT Nature

		NAT	VOC	Nature
11	1	0		NATURE - DECIDUOUS FORESTS
11	1	1		NATURE - DECIDUOUS FORESTS : HIGH ISOPRENE EMITTERS
11	1	2		NATURE - DECIDUOUS FORESTS : LOW ISOPRENE EMITTERS
11	1	3		NATURE - DECIDUOUS FORESTS : NON ISOPRENE EMITTERS
11	10	0		NATURE - HUMANS
11	2	0		NATURE - CONIFEROUS FORESTS
11	3	0		NATURE - FOREST FIRES
11	4	0		NATURE - NATURAL GRASSLAND

NA Not Applicable

		NA	VOC Not Applicable
10	1	0	AGRICULTURE - CULTURES WITH FERTILIZERS except animal manure
10	1	1	AGRICULTURE - CULTURES WITH FERTILIZERS : PERMANENT CROPS
10	1	2	AGRICULTURE - CULTURES WITH FERTILIZERS : ARABLE LAND CROPS
10	1	3	AGRICULTURE - CULTURES WITH FERTILIZERS : RICE FIELD
10	1	4	AGRICULTURE - CULTURES WITH FERTILIZERS : MARKET GARDENING
10	1	5	AGRICULTURE - CULTURES WITH FERTILIZERS : GRASSLAND
10	1	6	AGRICULTURE - CULTURES WITH FERTILIZERS : FALLOWS
10	2	0	AGRICULTURE - CULTURES WITHOUT FERTILIZERS
10	2	1	AGRICULTURE - CULTURES WITHOUT FERTILIZERS : PERMANENT CROPS
10	2	2	AGRICULTURE - CULTURES WITHOUT FERTILIZ. : ARABLE LAND CROPS
10	2	3	AGRICULTURE - CULTURES WITHOUT FERTILIZERS : RICE FIELD
10	2	4	AGRICULTURE - CULTURES WITHOUT FERTILIZ. : MARKET GARDENING
10	2	5	AGRICULTURE - CULTURES WITHOUT FERTILIZERS : GRASSLAND
10	2	6	AGRICULTURE - CULTURES WITHOUT FERTILIZERS : FALLOWS
10	4	0	AGRICULTURE - ANIMAL BREEDING (enteric fermentation)
10	4	1	AGRICULTURE - ANIMAL BREEDING (enteric ferm.) : DAIRY COWS
10	4	2	AGRICULTURE - ANIMAL BREEDING (enteric ferm.) : OTHER CATTLE
10	4	3	AGRICULTURE - ANIMAL BREEDING (enteric fermentat.) : OVINES
10	4	4	AGRICULTURE - ANIMAL BREEDING (enteric fermentation) : PIGS
10	4	5	AGRICULTURE - ANIMAL BREEDING (enteric fermentat.) : HORSES
10	4	6	AGRICULTURE - ANIMAL BREEDING (enteric fermentation) : ASSES
10	4	7	AGRICULTURE - ANIMAL BREEDING (enteric fermentation) : GOATS
10	5	0	AGRICULTURE - ANIMAL BREEDING (excretions)
10	5	1	AGRICULTURE - ANIMAL BREEDING (excretions) : DAIRY COWS
10	5	10	AGRICULTURE - ANIMAL BREEDING (excretions) : FUR ANIMALS
10	5	2	AGRICULTURE - ANIMAL BREEDING (excretions) : OTHER CATTLE
10	5	3	AGRICULTURE - ANIMAL BREEDING (excretions) : FATTENING PIGS
10	5	4	AGRICULTURE - ANIMAL BREEDING (excretions) : SOWS
10	5	5	AGRICULTURE - ANIMAL BREEDING (excretions) : SHEEP
10	5	6	AGRICULTURE - ANIMAL BREEDING (excretions) : HORSES
10	5	7	AGRICULTURE - ANIMAL BREEDING (excretions) : LAYING HENS
10	5	8	AGRICULTURE - ANIMAL BREEDING (excretions) : BROILERS
10	5	9	AGRICULTURE - ANIMAL BREEDING (excretions) : OTHER POULTRY
11	5	0	NATURE - HUMID ZONES
11	5	1	NATURE - HUMID ZONES : UNDRAINED AND BRACKISH MARSHES
11	5	2	NATURE - HUMID ZONES : DRAINED MARSHES
11	5	3	NATURE - HUMID ZONES : RAISED BOGS
11	6	0	NATURE - WATERS
11	6	1	NATURE - LAKES
11	6	2	NATURE - SHALLOW SALTWATERS
11	6	3	NATURE - GROUND WATERS
11	6	4	NATURE - DRAINAGE WATERS
11	6	5	NATURE - RIVERS
11	6	6	NATURE - DITCHES AND CANALS
11	6	7	NATURE - OPEN SEA (> 6m)
11	7	0	NATURE - ANIMALS
11	7	1	NATURE - ANIMALS : TERMITES
11	7	2	NATURE - ANIMALS : MAMMALS
11	8	0	NATURE - VOLCANOES
11	9	0	NATURE - NEAR SURFACE DEPOSITS
4	3	4	PRODUCTION PROC. - MAGNESIUM
4	4	10	PRODUCTION PROC. - TITANIUM DIOXIDE

NA Not Applicable

		NA	VOC	Not Applicable
4	4	11		PRODUCTION PROC. - GRAPHITE
4	4	12		PRODUCTION PROC. - CALCIUM CARBIDE
4	4	5		PRODUCTION PROC. - AMMONIUM NITRATE
4	4	6		PRODUCTION PROC. - AMMONIUM PHOSPHATE
4	6	9		PRODUCTION PROC. - BARK GASIFIER
5	1	0		EXTRACTION AND 1ST TREATMENT OF SOLID FUELS
5	1	1		EXTRACT. AND 1ST TREAT. OF SOLID FUELS - OPEN CAST MINING
5	1	2		EXTRACT. AND 1ST TREAT. OF SOLID FUELS - UNDERGROUND MINING
5	1	3		EXTRACT. AND 1ST TREAT. OF SOLID FUELS - STORAGE
9	5	0		WASTE TREATMENT AND DISPOSAL - COMPOST PRODUCTION FROM WASTE
9	8	0		WASTE TREATMENT AND DISPOSAL - LATRINES

7 ANNEX 2

Explanation of abbreviations *(codes)* used in RAINS-*VOC* model

Types of explanatory variables used in RAINS-VOC model

Name	*Code*	*Unit*
Brown coal/lignite, high grade	BC1	PJ
Brown coal/lignite, low grade	BC2	PJ
Hard coal, high quality	HC1	PJ
Hard coal, medium quality	HC2	PJ
Hard coal, low quality	HC3	PJ
Derived coal (coke, briquettes)	DC	PJ
Other solid-low S (biomass, waste, wood)	OS1	PJ
Other solid-high S (incl. high S waste)	OS2	PJ
Heavy fuel oil	HF	PJ
Medium distillates (diesel,light fuel oil)	MD	PJ
Light fractions (gasoline,kerosen,naphta,LPG)	LF	PJ
Natural gas (incl. other gases)	GAS	PJ
Renewable (solar, wind, small hydro)	REN	PJ
Hydro	HYD	PJ
Nuclear	NUC	PJ
Electricity	ELE	PJ
Heat (steam, hot water)	HT	PJ
Textiles (clothing)	TEX	kt
Solvents	SLV	kt
Population	POP	mln cap
Paint use	PNT	kt
Vehicles	VEH	kveh
Paint and glue produced	PG	kt
Emissions of NMVOC	EMI	kt
Crude oil	CRU	Mt

Sectors distinguished in the RAINS-VOC model

Code	*Name*
CAR_EVAP	Evaporative emissions from cars
EXD_GAS	Extraction, processing and distribution of gaseous fuels
EXD_GAS_NEW	Distribution of gaseous fuels - new mains
EXD_LQ	Extraction, processing and distribution of liquid fuels
EXD_LQ_NEW	Extraction, processing, distribution of liquid fuels *(including new Loading and Unloading practices)*
REF_PROC	Refineries - process
D_GASST	Gasoline distribution - service stations
D_REFDEP	Gasoline distribution - transport and depots (including storage at refinery)
DRY	Dry cleaning
DRY_NEW	Dry cleaning (new installations)
DEGR	Degreasing
DEGR_NEW	Degreasing (new installations)
VEHTR	Treatment of vehicles (underseal treatment and dewaxing)
DOM_OS	Domestic use of solvents (other than paint)
ARCH_P	Architectural use of paints
DOM_P	Domestic use of paints
AUTO_P	Manufacture of automobiles
AUTO_P_NEW	Manufacture of automobiles (new installations)
VEHR_P	Vehicle refinishing
VEHR_P_NEW	Vehicle refinishing (new installations)
IND_P	Other industrial use of paints
PIS	Products incorporating solvents
PNIS	Products not incorporating solvents
PHARMA	Pharmaceutical industry
PRT_PACK	Flexography and rotogravure in packaging
PRT_PACK_NEW	Flexography and rotogravure in packaging (new installations)
PRT_OFFS	Printing, offset
PRT_OFFS_NEW	Printing, offset (new installations)
PRT_PUB	Rotogravure in publication
PRT_PUB_NEW	Rotogravure in publication (new installations)
PRT_SCR	Screen printing
PRT_SCR_NEW	Screen printing (new installations)
IND_OS	Other industrial use of solvents
WOOD	Preservation of wood
WOOD_NEW	Preservation of wood (new installations)
GLUE	Application of glues and adhesives in industry
INORG	Inorganic chemical industry
ORG_PROC	Organic chemical industry, process
ORG_STORE	Organic chemical industry, storage
PP_EX_WB	Power plants, existing wet bottom
PP_EX_OTH	Power plants, existing other
PP_NEW	New power plants
CON_COMB	Conversion
IN_BO	Industrial boilers
IN_OC	Other industrial combustion
RESID	Combustion in residential and commercial sector

Sectors distinguished … *continued*

Code	***Name***
FOOD	Food and drink industry
AGR_BURN	Stubble burning and other agricultural waste
IND_OTH	Other industrial sources
WASTE	Waste treatment and disposal
TRA_OTS_M	Transport other, medium size ships
TRA_OTS_L	Transport other, large size ships
TRA_RD_LF2	Transport road - two-stroke engines
TRA_OT_LF2	Transport other - two-stroke engines
TRA_AIR	Air transport (LTO)

Codes of control technologies distinguished in RAINS-VOC model

Name of control option	*Code*
No control	NoC
Quarterly inspection and maintenance programs	LK_I
Monthly inspection and maintenance programs	LK_II
Covers on oil/water separators	COWS
Incineration of emissions in a flare and incinerator	FLR-I
Quarterly inspection, covers on oil/water separators, flaring	LK_I+CS+FLR
Monthly inspection, covers on oil/water separators, flaring	LK_II+CS+FLR
Quarterly inspection, covers on oil/water separator, flaring, incineration	LK_I+CS+FLR-I
Monthly inspection, covers on oil/water separator, flaring, incineration	LK_II+CS+FLR-I
Small carbon canister (in cars)	SCC
Stage II controls at service stations	ST_II
Stage IB controls at service stations	ST_IB
Stage II and IB at service station	ST(II+IB)
Internal floating covers or secondary seals	IFC
Stage IA (single stage) at gasoline depots	ST_IAS
Stage IA (double stage) at gasoline depots	ST_IAD
IFC and Stage IA (single stage) controls	IFC+ST_IAS
IFC and Stage IA (double stage) controls	IFC+ST_IAD
Vapor balancing on tankers and loading facilities	VBAL
Alternatives and increased recovery for venting	V_ALT
Improved ignition systems on flares	F_IMP
Vapor balancing and alternatives for venting	VBAL+V_ALT
Vapor balancing and alternatives for venting and flaring	VBAL+VF_ALT
Good housekeeping and carbon adsorption	HSE+ACA
Conventional closed circuit machine	CCCM
New generation closed circuit machine	NCCM
Activated carbon adsorption	ACA
Basic emissions management techniques	BEMT
Water-based system, degreasing	WBS
Low temperature plasma process	LTPP
Conveyored degreaser with integrated carbon adsorption	CD_ACA
Basic emissions management techniques and carbon adsorption	BEMT+ACA
Basic emissions management techniques and water-based system	BEMT+WBS
Basic emissions management, conveyored degreaser with ACA	BEMT+CD_ACA
Basic management, water system, conveyored degreaser with ACA	BEMT+WBS+CD_ACA
Basic management, water system, adsorption	BEMT+WBS+ACA
Plasma process, water system, basic emission management	LTPP+WBS+BEMT
Water-based system, adsorption	WBS+ACA
Conveyored degreaser with ACA, water-based system	WBS+CD_ACA
Water-based system, plasma process	WBS+LTPP
Product reformulation	REF
Propellant insert - e.g. replacement with nitrogen	P_INS
Product reformulation and propellant insert	REF+P_INS
Water-based paints (not emulsions)	WB
High-solids paints	HS
Emulsions, water-based dispersion paints	EMU
Emulsions and high-solids paints	EMU+HS

Codes of control technologies… *continued*

Name of control option	*Code*
Emulsions and water-based paints	EMU+WB
Emulsions, water-based and high-solid paints	EMU+WB+HS
Process modification and substitution	PRM+SUB
Adsorption, incineration	A_INC
Process modification, substitution, adsorption, incineration	PRM+SUB+A_INC
High volume low pressure spray guns	HVLP
Improved application (HVLP) and other primary (SMP, gunwash)	HAMP
Primary measures and 25% of high solids and water based paints	HAMP+SUB1
Substitution with 40% high solids, 60% water based paints	SUB2
Primary measures and 40% high solids, 60% water based paints	HAMP+SUB2
Good housekeeping and improved application (primary measures)	HAM
Substitution of high solvent with low solvent products	SUB
Good housekeeping, improved application and substitution	HAM+SUB
Good housekeeping, improved application and end-of-pipe	HAM+A_INC
Primary measures, end-of-pipe and substitution on remaining capacity	HAM+A_INC-SUB
Basic emission management measures, adsorption or incineration	BEMT+A_INC
Emission management, reformulation, adsorption or incineration	REF+BEMT+A_INC
Solvent management plan and substitution	SMP+SUB
Solvent management, substitution, adsorption or incineration	SMP+SUB+A_INC
Good housekeeping	HSE
Incineration	INC
Good housekeeping and catalytic or thermal incineration	HSE+INC
Switch from cutback to emulsion bitumen (road paving)	BISUB
Good housekeeping in steel industry and switch to emulsion bitumen	HSE+BISUB
Ban of stubble burning	BAN
Improved landfills	I_LAND
Flaring	FLR
Quarterly inspection and maintenance programs and flaring	LK_I+FLR
Quarterly inspection and maintenance programs and incineration	LK_I+INC
Quarterly inspection and maintenance, flaring, incineration	LK_I+FLR+INC
Monthly inspection and maintenance programs and flaring	LK_II+FLR
Monthly inspection and maintenance programs and incineration	LK_II+INC
Monthly inspection and maintenance, flaring, incineration	LK_II+FLR+INC
Vapor recovery unit (single stage)	VRU_I
Vapor recovery unit (double stage)	VRU_II
Internal floating covers or secondary seals, vapor recovery (single stage)	IFC+VRU_I
Internal floating covers or secondary seals, vapor recovery (double stage)	IFC+VRU_II
Good housekeeping and substitution	HSE+SUB
Good housekeeping, substitution, thermal or catalytic incineration	HSE+SUB+INC
Process modification	PRM
Process modification and biofilatration	PRM+BIO
Waterborne coating for leather	WBC
Agrochemicals - new products	NAGR
Primary, biofiltration, waterborne coating and new agrochemical	P_BIO+WBC+NAGR
Double vacuum impregnation system and enclosure of the dryer	DVS+ENC
Double vacuum impregnation, dryer enclosure, adsorption	DVS+ENC+ACA
Double vacuum impregnation, dryer enclosure, incineration	DVS+ENC+INC

Codes of control technologies… ***continued***

Name of control option	*Code*
Low solvent inks	LSI
Water based inks	WBI
Low solvent or water based inks	LSWBI
Low solvent inks and enclosure	LSI+ENC
Enclosure and incineration	ENC+INC
Enclosure and adsorption	ENC+ACA
Low solvent inks, enclosure and incineration	LSI+ENC+INC
Low solvent inks, enclosure and adsorption	LSI+ENC+ACA
Water based inks, enclosure and incineration	WBI+ENC+INC
Water based inks, enclosure and adsorption	WBI+ENC+ACA
Low solvent/water based inks, enclosure and incineration	LSWBI+ENC+INC
Low solvent/water based inks, enclosure and adsorption	LSWBI+ENC+ACA
Low solvent inks, enclosure and incineration or adsorption	LSI+ENC+INC-ACA
Water based inks, enclosure and incineration or adsorption	WBI+ENC+INC-ACA
Low solvent/water based inks and incineration/adsorption	LSWBI+ENC+INC-A
Water based inks, incineration (for new installations with enclosure)	WBI+INC
Primary measures in offset printing, including enclosure	PMOF
Solvent free inks and solvent management plant	SF+SMP
Primary measures (offset) and incineration	PMOF+INC
Primary measures (offset) and solvent free inks	PMOF+SF
Primary measures (offset), solvent free inks, incineration	PMOF+SF-INC
Water based inks and biofiltration (large installations)	WBI+BIO
Water based inks, enclosure and incineration or biofltration	WBI+ENC+INC-BIO
New, improved small (residential) boiler with accumulator tank	NB
Oxidation catalyst for small (residential) combustion boilers	CAT
New boiler and oxidation catalyst	NB+CAT
Oxidation catalyst for two-stroke engines	OX_CAT